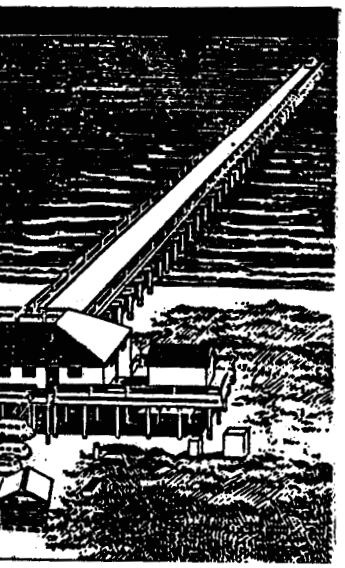
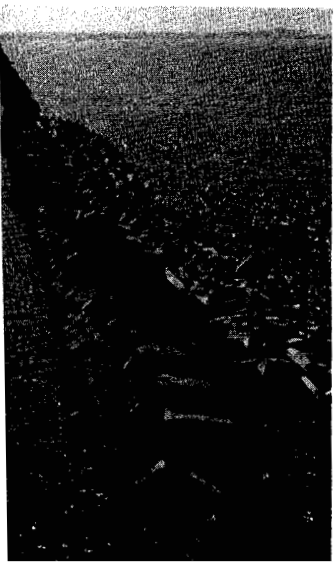
US Army Corps of Engineers





REMR RESEARCH PROGRAM

REPAIR, EVALUATION,, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CO-3

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES

Report 3
NORTH CENTRAL DIVISION

by

Robert R. Bottin, Jr.

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

June 1988

Report 3 of a Series

Prepared fa DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit 32278 and Work Unit 31269

The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehiabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics,	OM	Operations Management
CO	Coastal		

Destroy this report when no longer needed. Do not return it to the originator.

The fiindings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

COVER PHOTOS:

TOP — Field Research Facility, Duck, North Carolina.

BOTTOM — View of 2-ton dolos at the west end of Cleveland Harbor East Breakwater, Cleveland, Ohio.

Unclassifi
CURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OM8 No 0704.0188
Exp Date Jun 30, 1986

a REPORT SECURITY CLASSIFICATION
Unclassified

1b RESTRICTIVE MARKINGS

a SECURITY CLASSIFICATION AUTHORITY

3 DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited

b DECLASSIFICATION/ DOWNGRADING SCHEDULE

PERFORMING ORGANIZATION REPORT NUMBER(S)
Technical Report REMR-CO-3

5 MONITORING ORGANIZATION REPORT NUMBER(S)

a NAME OF PERFORMING ORGANIZATION
USAEWES, Coastal Engineering Research Center

6b OFFICE SYMBOL (If applicable)

7a NAME OF MONITORING ORGANIZATION

c ADDRESS (City, State. and ZIP Code)
PO Box 631
Vicksburg, MS 39180-0631

7b ADDRESS (City, State, and ZIP Code)

a NAME OF FUNDING/SPONSORING ORGANIZATION
US Amy Corps of Engineers

8b OFFICE SYMBOL (If applicable)

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

c. ADDRESS (City, State, and ZIP Code)
Washington, DC 20314-1000

10. SOURCE OF FUNDING NUMBERS — See reverse.

PROGRAM ELEMENT NO.	PROJEC NO.	TASK NO.	WORK UNIT ACCESSION NO

1 TITLE (Include Security Classification)
Case Histories of Corps Breakwater and Jetty Structures; Report 3: North Central

14. DATE OF REP
June 198

15. PAGE COUNT
437

FIELD	GROUP	SUB-GROUP

Breakwater
Concrete armor units
Jetty
REMR (Repair, Evaluation, Maintenance, and Rehabilitation)
Rubble-Mound structures

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL

22b TELEPHONE (Include Area Code)

22c OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

10. SOURCE OF FUNDING NUMBERS (Continued),

Work Unit 32278 and Work Unit 31269.

PREFACE

This report was prepared as part of the Coastal Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was carried out jointly under Work Unit **32278,** "Rehabilitation of Rubble-Mound Structure Toes," of the REMR Program and Work Unit **31269,** "Stability **of** Breakwaters," of the Civil Works Coastal Area Program. For the REMR Program, Problem Area Monitor is Mr. John H. Lockhart, Jr., Office, Chief of Engineers (OCE), US Army Corps of Engineers (Corps). REMR Program Manager is Mr. William F. McCleese of the US **Army** Engineer Waterways Experiment Station's (WES's) Structures Laboratory, and Coastal Problem Area Leader is Mr. D. D. Davidson of WES's Coastal Engineering Research Center (CERC). Messrs. John G. Housley and Lockhart, OCE, are Technical Monitors of the Civil Works Coastal **Program** and Dr. Linwood **C.** Vincent is **CERC** Program Manager.

This report is third in a series of case histories of Corps breakwater and jetty structures at nine Corps divisions. The case histories contained herein were extracted from information obtained from several sources (where available) which included inspection reports, conferences, telephone conversations, project plans and specifications, project files and correspondence, design memorandums, literature reviews, model studies, surveys (bathymetric and topographic), survey reports, annual reports to the Chief of Engineers, House and Senate documents, and general and aerial photography. Unless otherwise noted, only prominent changes to the prototype structures subsequent to March **1986** are included in this report.

This work was conducted at WES during the period April **1985** - January **1987** under general direction **of** Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and under direct supervision of Mr. C. Eugene Chatham, Jr., Chief, Wave Dynamics Division (CW), and Mr. D. D. Davidson, Wave Research Branch (CW-R), CW. This report was prepared by Mr. Robert R. Bottin, Jr., CW. Messrs. Robert D. Carver, Dennis *G.* Markle, R. Clay Baumgartner, C. Ray Herrington, and Willie G. Dubose, CW-R, conducted site inspections and collected much of the data contained herein. This report was typed by Ms. Myra E, Willis, CW-R, and edited by Ms. Shirley **A.** J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne *G.* Lee, CE, was Commander and Director of WES during the publication of this report; Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	*0.3048*	metres
inches	*2.54,*	centimetres
miles (US statute)	*1.609347*	kilometres
pounds (mass)	*0.4535924*	kilograms
tons (2,000 pounds, mass)	*907.1847*	kilograms

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES

NORTH CENTRAL DIVISION

PART I: INTRODUCTION

Background

1. The Corps of Engineers (Corps) is responsible for a wide variety of coastal structures located along the Atlantic and Pacific Oceans, the gulf coast, the Great Lakes, the Hawaiian Islands, other islands, and inland waterways. Coastal improvements such as breakwaters and/or jetties are necessary to provide harbor protection and the safe passage of vessels. These structures are usually constructed on movable-bed materials and are continuously subjected to wave and current forces. Under these conditions, structural deterioration may occur and, in time, maintenance may be required when the structure fails to serve the needs of the project. Some projects have been maintained for **150** years or more. Methods of construction (and repair) have varied significantly during this time principally because of a better understanding of coastal processes, availability of construction materials, existing wave climates, regional construction practices, and economic considerations.

Purpose

2. The purposes of this report are to lend insight into the scope, magnitude, and history of coastal breakwaters and jetties under Corps jurisdiction; to determine their maintenance and repair history; to determine their methods of construction; to make this information available to Corps personnel; and to address objectives of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. To this end, case histories of Corps breakwater and jetty structures have been developed to quantify past and present problem areas (if any), steps taken to rectify these problems, and subsequent evaluation of the remedial measures. General design guidance can be obtained from the solutions that have been most successful. Information in this report should be of particular value to Corps personnel in the US Army

Engineer Division, North Central (NCD), and its coastal districts and possibly to non-Corps personnel. Further research is being conducted to address problems where adequate solutions are lacking or where specific guidance is required (i.e. general armor stability, toe protection, localized damage, use of dissimilar armor, wave runup, and overtopping).

PART II: SUMMARY OF CORPS BREAKWATER AND JETTY STRUCTURES IN NCD

3. NCD has a total of *107* projects located in the Great Lakes region which include breakwater and/or jetty structures. NCD refers to many structures as piers which actually function as jetties. Therefore, the term "pier" used in this report will carry the same meaning as the term "jetty." Seventy of the projects are within US Army Engineer District, Detroit's (NCE's), area of responsibility; six are located within US Army Engineer District, Chicago's (NCC's) boundaries; and thirty-one are under the jurisdiction of US Army Engineer District, Buffalo (NCB). Figures 1-3 show the locations of these projects along the Great Lakes. Overall, there is a total of about *481,570* lin ft* of breakwater and/or jetty structures in NCD. Breakwaters account for approximately *69* percent of this total, and jetty structures account for the remaining 31 percent. Construction materials used for these structures include stone, concrete, steel sheetpiling, woodpiling, timber, and concrete armor units (dolosse used at Cleveland Harbor, Ohio).

4. Twenty-one projects are located on the United States shoreline of Lake Superior, thirty-eight on the Lake Michigan shoreline, fifteen on the Lake Huron shoreline, one on the Lake St. Clair shoreline (small lake between Lake Huron and Lake Michigan), twenty-two on the southern shore of Lake Erie, and ten on the Lake Ontario shoreline. Structures within NCD have experienced problems in all four major REMR problem areas (runup and overtopping, localized damage, toe stability, and use of dissimilar armor). Many of NCD's projects have deteriorated and have been repaired or modified since construction.

5. Breakwaters and jetties in NCD have been constructed on top of existing sediments (usually fine to coarse sand) in water depths ranging from *8* to *70* ft. These structures have crest elevations (el) ranging from 4 to 18 ft and crest widths ranging from 1 to about *60* ft. Side slopes of stone structures range from 1V:1.25H to 1V:2H. Design guidance for breakwater cross-sections (stone sizes, crest height, width, etc.) is provided by the Shore Protection Manual (SPM) *(1984)* or other appropriate Corps engineering manuals. Several of NCD's projects have been model tested at the US Army Engineer Waterways Experiment Station.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

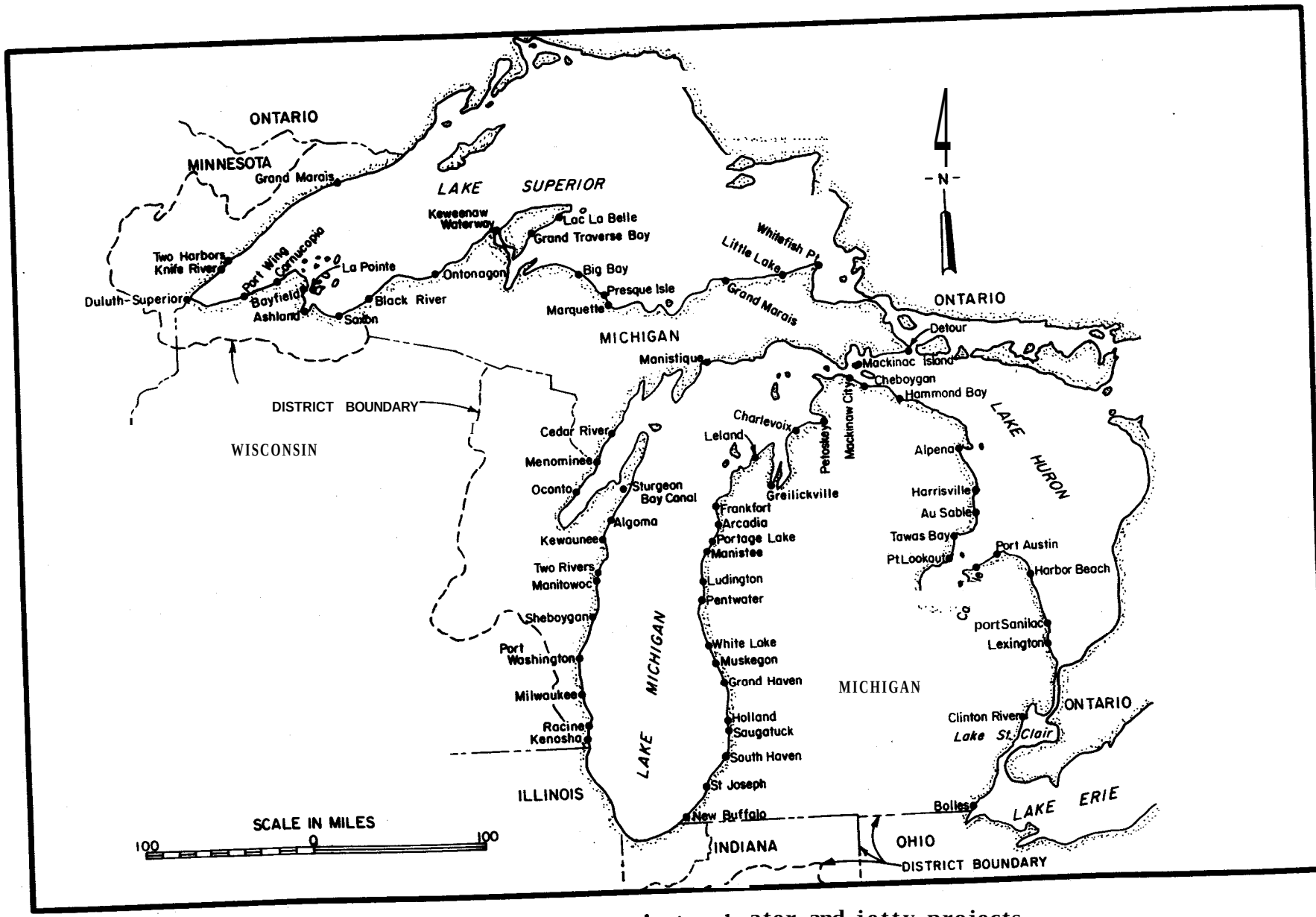


Figure 1. Location of NCE's breakwater and jetty projects

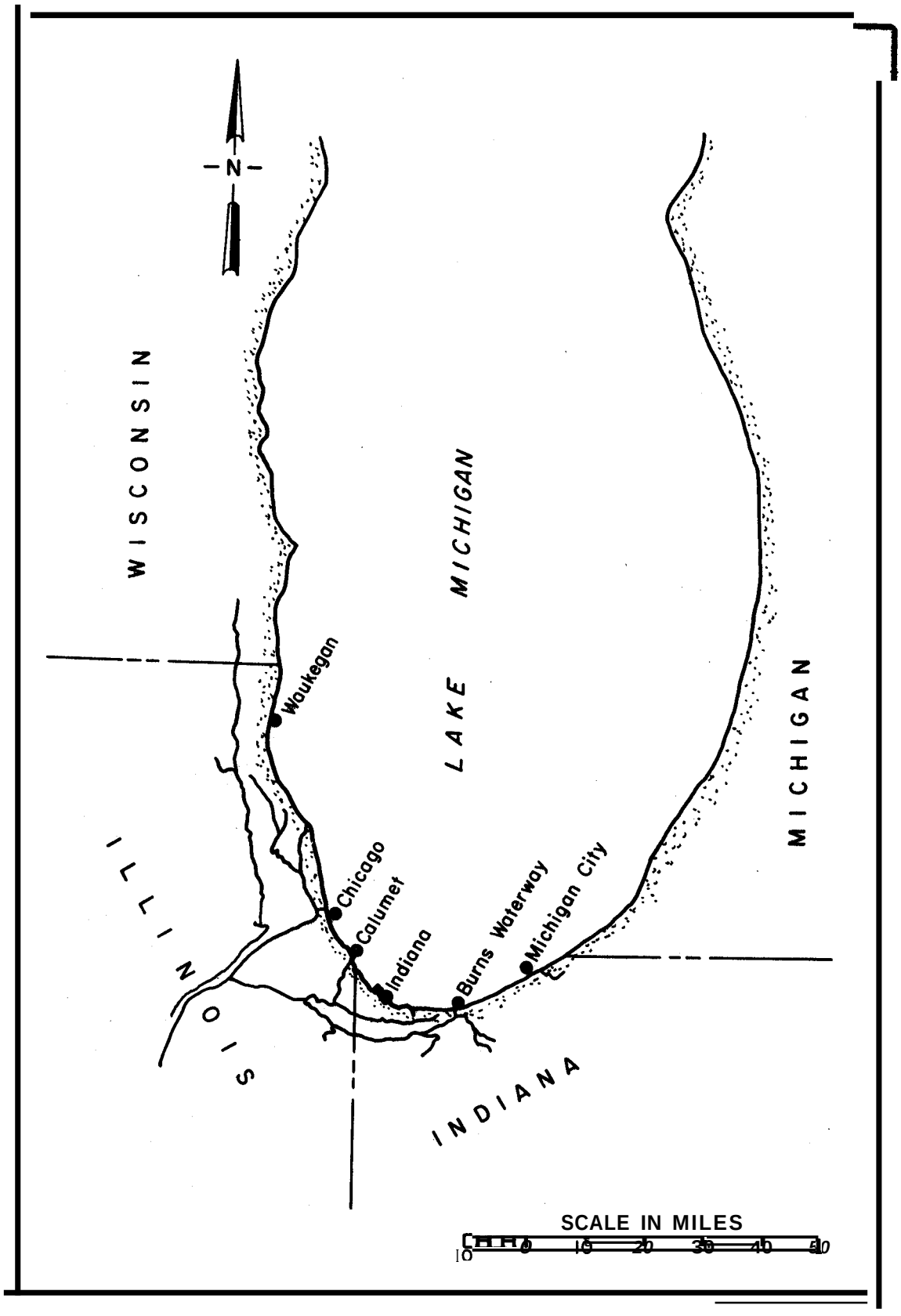


Figure 2. Location of NCC's breakwater and jetty projects

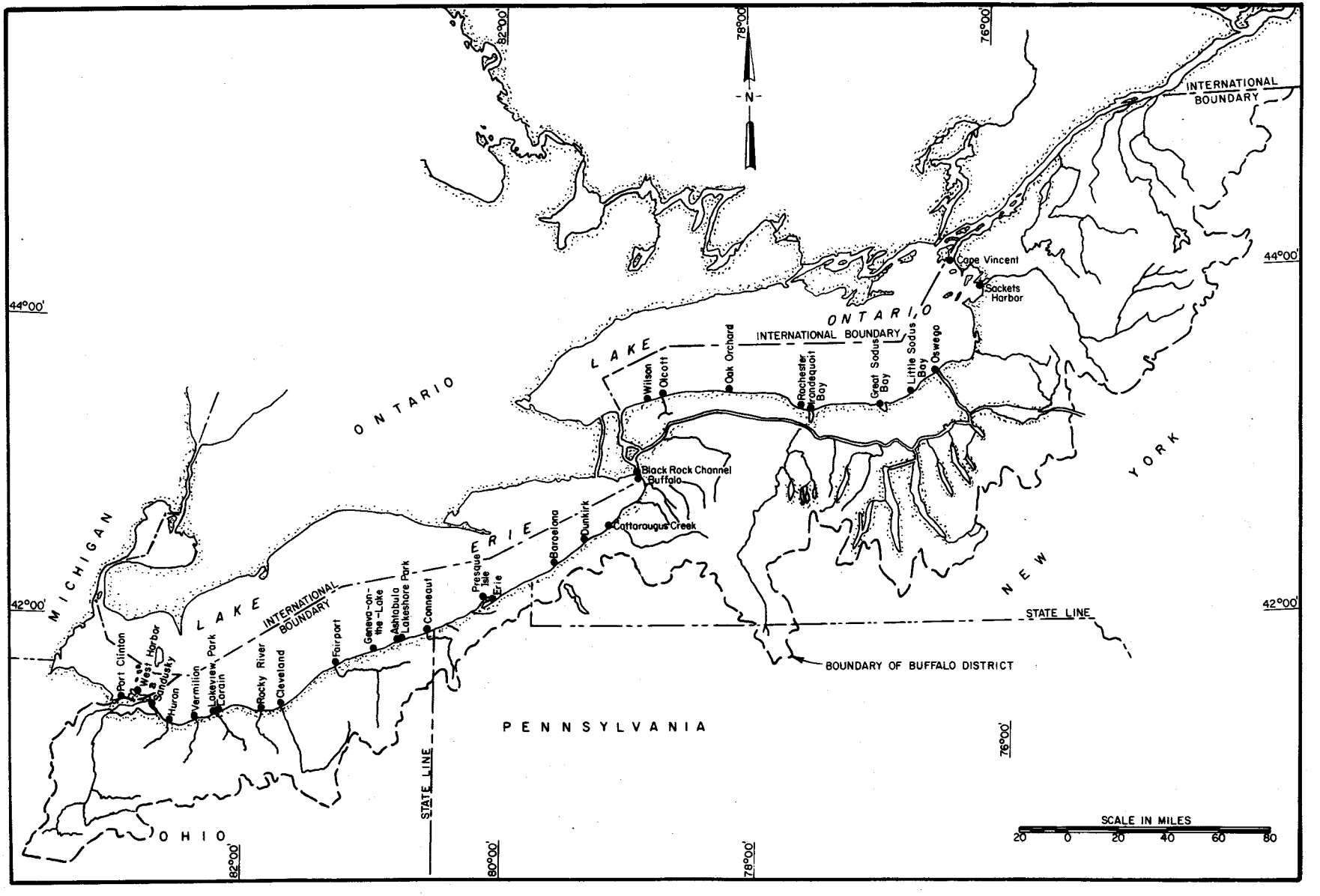


Figure 3. Location of NCB's breakwater and jetty projects

6. The els of various structures and depths on the Great Lakes are based on low water datum (lwd) which is referenced to mean water level (mwl) at Father Point, Quebec, according to the International Great Lakes Datum (IGLD) of 1955. Figure 4 shows a profile of the Great Lakes region. Horizontal and vertical distances have been distorted somewhat to convey visual impression.

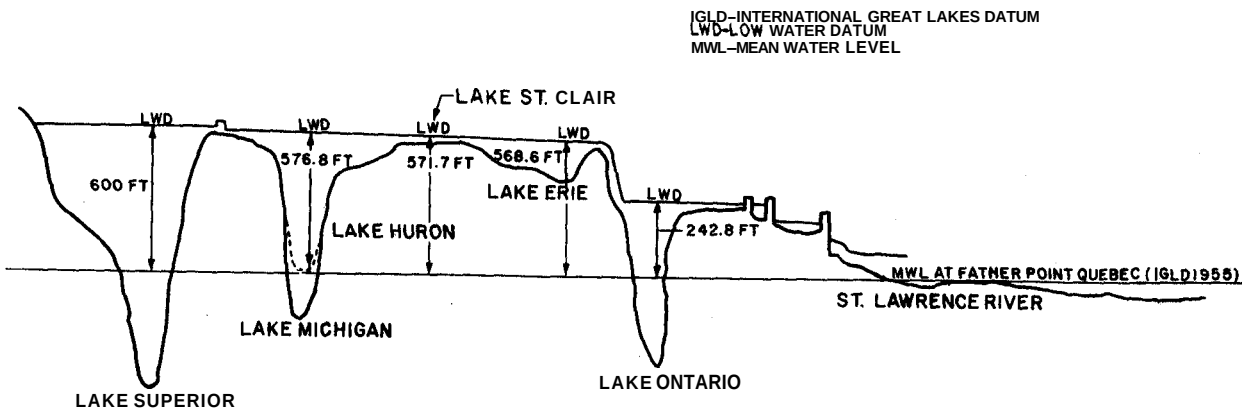


Figure 4. Profile of the Great Lakes region (lwd referenced to mwl at Father Point, Quebec according to IGLD of 1955)

7. Case histories for NCD's breakwater and jetty structures are presented in Tables 1-107. Figures depicting structure alignments, cross sections, and aerial photographs for some sites accompany the various tables. Sites are presented in the order of west to east and counterclockwise along the lake shoreline (i.e., the first site being presented on the northwest end of Lake Superior and the last on the east coast of Lake Ontario). General characteristics of the structures at the various sites are shown in the following tabulation:

Table	Location	Structure Type & No.*	Construction Materials**	Structure Length ft	Date of Origin	Improvement†
			Lake Superior			
1	Grand Marais Harbor, Minn.	B(3)	TC,S,C,CC	1,719	1883	M
2	Two Harbors, Minn.	B(2)	TC,S,CC	2,528	1893	M
3	Knife River Harbor, Minn.	B(2)	TC,S,TD	245	1957	M
4	Duluth-Superior Harbor, Minn. and wis.	B(2) P(4)	TC,S,C,CC,SSP	13,650	1898	R
5	Port Wing Harbor, wis.	P(2)	WP,S,CC,SSP	1,806	1903	R
6	Cornucopia Harbor, wis.	P(2)	WP,SSP,S,CSSP	1,468	1957	N
7	Bayfield Harbor, wis,	B(2)	CSSP,S	242	1936	N
8	La Pointe Harbor, wis.	B(1)	CSSP,S,SSP	200	1967	N
9	Ashland Harbor, wis.	B(1)	TC,S,CC	8,000	1889	N
10	Saxon Harbor, Wis.	B(2)	S,SSP,CSSP	1,033	1965	N
11	Black River Harbor, Mich.	B(2)	S	1,380	1957	N
12	Ontonagon Harbor, Mich.	P(2)	TC,S,WP,SSP, C,CC	4,782	1868	N

(Continued)

* Type (B - breakwater, J - jetty, and P - pier) and number of structures (i.e., B(3) indicates 3 breakwaters).

** C - concrete, CC - concrete cap, S - stone, TD - timber deck, TC - timber crib, WP - wood piling, CSSP - cellular steel sheet pile, SSP - steel sheet pile.

† M - modification, R - rehabilitation, N - none, D - dolosse, Z-W - Z-wall, G - Gabion, SP - Sta-pod.

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Superior (Continued)			
13	Keweenaw Waterway, Mich.	B(3)	TC,S,SSP,C,	8,844	1860	N
14	Lac La Belle Harbor, Mich.	B(2)	SSP,CSSP,S	1,179	1959	N
15	Grand Traverse Bay Harbor, Mich.	P(2)	SSP,CSSP,S, CC	1,618	1949	M
16	Big Bay Harbor, Mich.	B(2)	S,SSP,CSSP	1,258	1960	R
17	Presque Isle Harbor, Mich.	B(1)	TC,S,C	2,816	1897	R
18	Marquette Harbor, Mich.	B(1)	TC,S,CC	4,510	1867	R
19	Grand Marais Harbor, Mich.	P(2)	TC,S,CC,WP, CSSP	4,409	1883	R
20	Little Lake Harbor, Mich.	B(2)	S,CSSP	1,270	1964	N
21	Whitefish Point Harbor, Mich.	B(3)	CSSP,SSP,S, CC	1,364	1968	N
			Lake Michigan			
22	Manistique Harbor, Mich.	B(2) P(1)	TC,S,CC,WP	4,046	1887	M,R
23	Cedar River Harbor, Mich.	P(2)	WP,S	1,100	1883	M
24	Memominee Harbor, Mich.	P(2)	WP,S,C,CC,SSP	3,912	1871	R
25	Oconto Harbor, Wis.	P(1)	WP,S,CSSP,CC	2,144	1883	R
26	Sturgeon Bay Canal, wis.	B(2)	TC,CC,S,WP	2,688	1873	N

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Michigan (Continued)			
27	Algoma Harbor, Wis.	P(1) B(2)	WP,TC,CC,S	2,632	1871	N
28	Kewaunee Harbor, wis.	P(2) B(1)	WP,SSP,S,CC	5,456	1881	R
29	Two Rivers Harbor, wis.	P(2)	WP,TC,S,CC	3,313	1872	R
30	Manitowoc Harbor, wis.	P(1) B(2)	WP,TC,S,C,CC	4,904	1895	R
31	Sheboygan Harbor, wis.	P(2) B(1)	WP,TC,S,CC	6,443	1873	R
32	Port Washington Harbor, Wis.	B(3)	S,C,CSSP, SSP,WP	4,713	1934	M
33	Milwaukee Harbor, wis.	P(2) B(2)	TC,S,C,CC, SSP,WP	22,882	1855	R
34	Racine Harbor, Wis.	P(2) B(2)	TC,S,C,CC, WP,SSP	5,509	1900	R
35	Kenosha Harbor, wis.	P(2) B(1)	TC,C,CC,WP, SSP	3,048	1899	R
36	Waukegan Harbor, I11.	P(2) B(1)	TC,C,CC,S, WP,SSP	6,545	1903	M,R
37	Chicago Harbor, I11.	P(1) B(2)	TC,C,CC,SSP, S	20,351	1874	M,R
38	Calumet Harbor, I11. and Ind.	B(2)	TC,S,CC,CSSP	11,721	1904	R
39	Indiana Harbor, Ind.	B(2)	S,C	3,645	1922	M
40	Burns Waterway Harbor, Ind.	B(1)	S	5,830	1968	R

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
		Lake Michigan (Continued)				
41	Michigan City Harbor, Ind.	B(2) P(2)	TC, S, CC, SSP, WP	5,415	1884	R
42	New Buffalo Harbor, Mich.	B(2)	S, SSP	2,045	1975	R
43	Saint Joseph Harbor, Mich.	P(2)	TC, CC, SSP, WP, S	5,361	1836	R
44	South Haven Harbor. Mich.	P(2)	TC, S, CC, SSP, WP	2,395	1868	R
45	Saugatuck Harbor, Mich.	P(2)	TC, S, CC, SSP, WP	5,016	1904	R
46	Holland Harbor, Mich.	B(2) P(2)	TC, S, CC, SSP, WP	2,953	1868	R
47	Grand Haven Harbor, Mich.	P(2)	TC, S, CC, SSP, WP	2,931	1867	R
48	Muskegon Harbor, Mich.	B(2) P(2)	C, S, CC, WP, SSP	7,480	1868	M, R
49	White Lake Harbor, Mich.	P(2)	TC, S, WP, CC	1,518	1870	N
50	Pentwater Harbor, Mich.	P(2)	S, TC, WP, CC	1,421	1868	M
51	Ludington Harbor, Mich.	B(2) P(2)	S, TC, CC, WP, SSP	8,069	1866	R
52	Manistee Harbor, Mich.	B(1) P(2)	TC, WP, SSP, S, CC	4,410	1912	R
53	Portage Lake Harbor, Mich.	P(2)	TC, S, CC, WP	2,632	1883	R
54	Arcadia Harbor, Mich.	P(2)	TC, S, SSP, CC	1,410	1909	R

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Michigan (Continued)			
55	Frankfort Harbor, Mich.	P(2) B(2)	TC,C,S,WP,CC, SSP, CSSP	6,027	1868	R
56	Leland Harbor, Mich.	P(1) B(1)	S,CSSP,SSP,WP	1,675	1936	M,R
57	Greilickville Harbor, Mich.	B(3)	SSP,S,CC,CSSP	2,005	1950	M
58	Charlevoix Harbor, Mich.	P(2)	TC,S,CSSP,WP CC,SSP	1,688	1872	R
59	Petoskey Harbor, Mich.	B(1)	TC,S,CC	1,250	1895	R
			Lake Huron			
60	Detour Harbor, Mich.	B(1)	S,CC	1,310	1982	N
61	Mackinac Island Harbors Mich.	B(2)	S	1,860	1914	M
62	Mackinaw City Harbor, Mich.	B(2)	S,C	630	1955	N
63	Cheboygan Harbor, Mich.	B(1)	S,C	775	1968	R
64	Hammond Bay Harbor, Mich.	B(2)	S	1,905	1965	R
65	Alpena Harbor, Mich.	B(1)	S	750	1939	M
66	Harrisville Harbor, Mich.	B(2)	S	2,780	1959	M,R
67	Au Sable Harbor, Mich.	J(2)	CSSP,SSP,S,CC	2,407	1962	R
68	Tawas Bay Harbor, Mich.	B(1)	SSP,CC,S	1,564	1977	N

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Huron (Continued)			
69	Point Lookout Harbor, Mich.	B(2)	S	7,800	1972	R
70	Caseville Harbor, Mich.	B(1)	S	1,780	1964	R
71	Port Austin Harbor, Mich.	B(1)	CSSP,S,CC	1,926	1959	R
72	Harbor Beach, Mich.	B(3)	TC,S,CC	7,876	1874	R
73	Port Sanilac Harbor, Mich.	B(2)	CSSP,S,CC, SSP	2,575	1951	M
74	Lexington Harbor, Mich.	B(2)	S	2,595	1976	N
			Lake St. Clair			
75	Clinton River, Mich.	B(1)	S	1,400	1966	N
			Lake Erie			
76	Bolles Harbor, Mich.	J(1)	S	400	1970	N
77	Port Clinton Harbor, Ohio	J(2)	S,WP,SSP,CC	3,330	1893	R
78	West Harbor, Ohio	B(2)	S,C	2,925	1982	N
79	Sandusky Harbor, Ohio	J(1)	S	6,000	1897	R
80	Huron Harbor, Ohio	P(1) B(1)	S,TC,CC,SSP, WP	4,973	1827	R
81	Vermilion Harbor, Ohio	P(2) B(1)	TC,S,CSSP,CC	2,656	1836	M,R
82	Lakeview Park, Ohio	B(3)	S	750	1977	N

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Erie (Continued)			
83	Lorain Harbor, Ohio	P(2) B(3)	TC,S,CC,CSSP	12,541	1828	M,R
84	Rocky River Harbor, Ohio	P(1)	S	900	1873	R
85	Cleveland Harbor, Ohio	P(2) B(2)	TC, S ,CC,D	32,560	1875	M,R
86	Fairport Harbor, Ohio	P(2) B(2)	TC,S,CC,SSP, C, CSSP	12,105	1868	M,R
87	Geneva-on-the-Lake, Ohio	B(3)	SP,G,Z-W	270	1978	N
88	Ashtabula Harbor, Ohio	B(3)	S,TC	13,051	1897	M,R
89	Lakeshore Park, Ohio	B(3)	S	375	1983	N
90	Conneaut Harbor, Ohio	P(1) B(2)	S,CSSP,TC,CC	11,100	1894	M,R
91	Presque Isle Peninsula, Pa.	B(3)	S	375	1978	N
92	Erie Harbor, Pa.	P(2)	TC,S,CC,SSP	5 ,463	1825	R
93	Barcelona Harbor, N.Y.	B(2)	CSSP,CC,S, SSP	2,057	1960	M
94	Dunkirk Harbor, N.Y.	P(1) B(3)	C,S,CC	6,888	1868	M,R
95	Cattaraugus Harbor, N.Y.	B(2)	S,C	2,450	1983	N
96	Buffalo Harbor, N.Y.	B(5)	TC, S , CC	24 ,433	1869	M,R
97	Black Rock Channel, N.Y.	P(1)	TC, S , CC,TD	10,507	1822	M,R

(Continued)

Table	Location	Structure Type & No.	Construction Materials	Structure Length ft	Date of Origin	Improvement
			Lake Ontario			
98	Wilson Harbor, N.Y.	P(2)	SSP,S,CC,TD, TC	1,331	1878	M,R
99	Olcott Harbor, N.Y.	P(2)	TC,SSP,S,CC, TD	1,723	1918	R
100	Oak Orchard Harbor, N.Y.	P(2) B(1)	S,CSSP, CC	2,120	1975	N
101	Rochester Harbor, N.Y.	P(2)	S,TC,SSP,CC	5,770	1835	R
102	Irondequoit Bay, N.Y.	B(1) J(1)	S	2,100	1985	N
103	Great Sodus Bay Harbor, N.Y.	P(2) B(1)	TC,S,SSP,CC	4,527	1910	R
104	Little Sodus Bay Harbor, N.Y.	P(2) B(1)	TC,S,SSP,CC	5,237	1867	R
105	Oswego Harbor, N.Y.	B(3)	TC, S, CC	10,265	1882	M,R
106	Sackets Harbor, N.Y.	J(1)	WP,S	164	1888	N
107	Cape Vincent Harbor, N.Y.	B(1)	TC,S,CC	1,381	1915	R

(Concluded)

Table 1

Grand Marais Harbor Breakwaters

Grand Marais, Minnesota

Date(s)	Construction and Rehabilitation History
1883-1884	A 300-ft-long rock-filled timber-crib breakwater was constructed at the site (Figure 5, Sections E and F) during this period. The outer 48 ft of the structure (Figures 5 and 6, Section E) was built 40 ft in width, and the remaining 252 ft (Figures 5 and 6, Section F) was constructed 30 ft in width.
1901-1902	A 350-ft-long rock-filled timber crib breakwater was constructed west of the first structure during this period (Figures 5 and 6, Section D). The structure was built 24 ft wide.
1925	A concrete cap (superstructure) was constructed on the outer 48 ft of the structure built during 1883-84. The crest el was +7 ft lwd (Figure 6, Section E).
1926	A concrete cap (superstructure) was completed on the 30-ft-wide, 252-ft-long structure built during 1883-84. The crest was constructed at an el of +7 ft lwd (Figure 6, Section F).
1933	A concrete cap (superstructure) was installed on the breakwater built during 1901-02. The crest el was +7 ft lwd. Heavy riprap was placed on both sides of the structure (Figure 6, Section D). Also in 1933 a 43-ft-long concrete breakwater connecting the east breakwater to shore was constructed (Figure 5, Section G). The structure was 12 ft wide and had a crest el of +7 ft lwd (Figure 6, Section G).
1959	Construction of a 921-ft-long rubble-mound inner breakwater was completed (Figure 5, Section A). Cover stone, a minimum of 2 tons, was placed on the outer 550 ft of the structure, and 1-ton (minimum) cover stone was placed on the remaining part of the breakwater. The crest el was +6 ft lwd with an 8-ft width. The structure had side slopes of 1V:1.5H (Figure 6, Section A). The inner breakwaters were model tested (Fenwick 1941, 1944).
1972	A 65-ft-long rubble-mound breakwater connecting the shore to an island (Figure 5, Section B) and a 40-ft-long rubble-mound breakwater connecting the island to the east breakwater (Figure 5, Section C) were constructed. These structures were built with stone ranging from 5 to 20 tons and had crest els of +6 ft lwd (Figure 6, Sections B and C). Model testing of these structures was conducted (Fenwick 1941).
1981	A survey of the structures revealed spalling of the concrete at several locations, particularly on the lakeside of the east breakwater. The rubble-mound shore connection of the west breakwater required

(Continued)

Table 1 (Concluded)

Date(s)	Construction and Rehabilitation History
	additional stone to raise the el in some locations above the water level. The concrete cap of the west breakwater was noted shifting, cracking, separating, and/or tilting in some locations. Concrete spalling also was noted.
1986	The general condition of the east and west breakwaters is considered fair. The rubble-mound inner breakwater is in good condition.

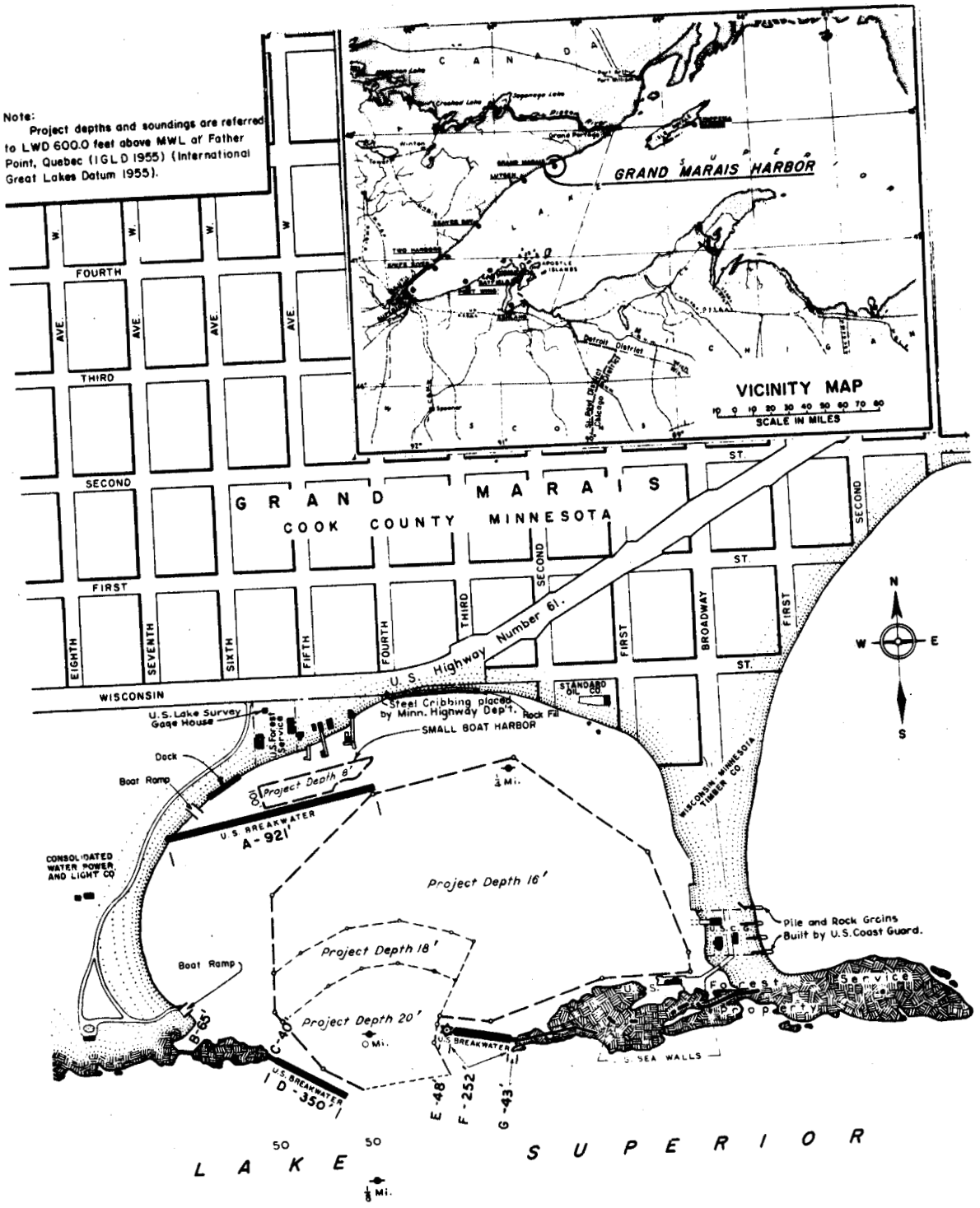


Figure 5. Grand Marais Harbor, Minnesota

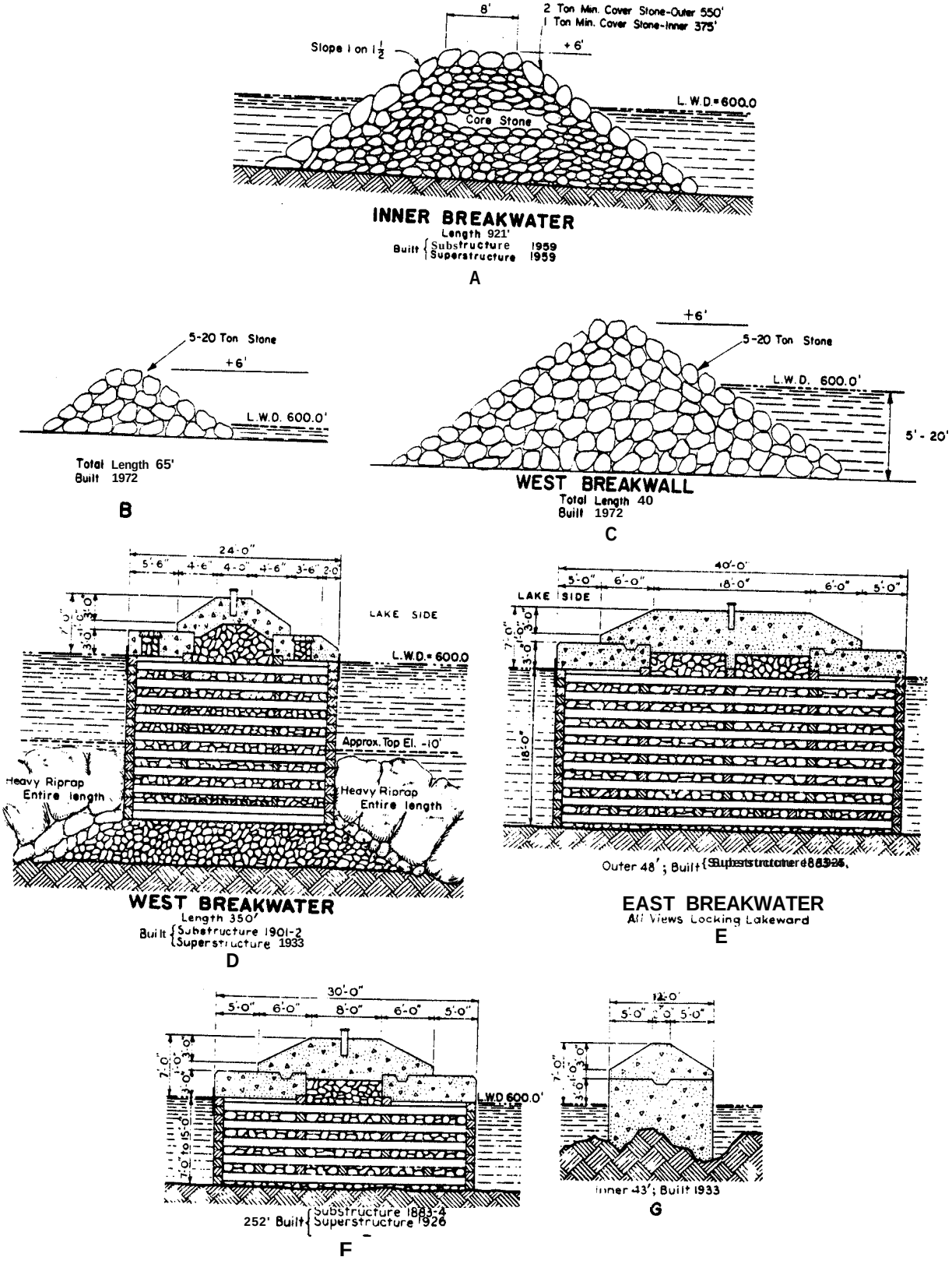


Figure 6. Typical breakwater cross sections, Grand Marais Harbor, Minnesota

Table 2

Two,Harbors Breakwaters

Two [rt Minnesota

Date(s)	Construction and Rehabilitation History
1893	Construction of a 900-ft-long stone-filled timber crib breakwafer (Figure 7, Sections C, D, and E) was completed at the site. The cribs were built on rubble-mound foundations. The easternmost 800 ft of the structure was 24 ft wide (Figure 8, Section C), the adjacent 50-ft portion was 20 ft wide (Figure 8, Section D), and the westernmost 50 ft of the breakwater was 16 ft wide (Figure 8, Section E).
1933-1934	A concrete cap (superstructure) was built on the breakwater. The crest el was +7 ft lwd (Figure 8, Sections C, D, and E).
1947-1949	A 1,302-ft-long stone-filled timber crib breakwater on a rubble-mound base was constructed (Figures 7 and 8, Section B). The structure was 30 ft wide. The rubble-mound base consisted of 5-ton cover stone on 1V:1.5H side slopes.
1948	Construction of a 326-ft-long rubble-mound shore connection of the east breakwater was completed (Figures 7 and 8, section A). The crest was 12 ft wide with a +6 ft crest el.
1948-1950	A concrete cap (superstructure) was built on the 1,302-ft-long breakwater that was completed during 1947-49 (Figure 8, Section B). The crest el of the structure was increased to +8 ft.
1986	Since construction, records indicate that localized damage of the breakwaters has occurred and has been repaired during routine maintenance. The structures are presently in good condition.

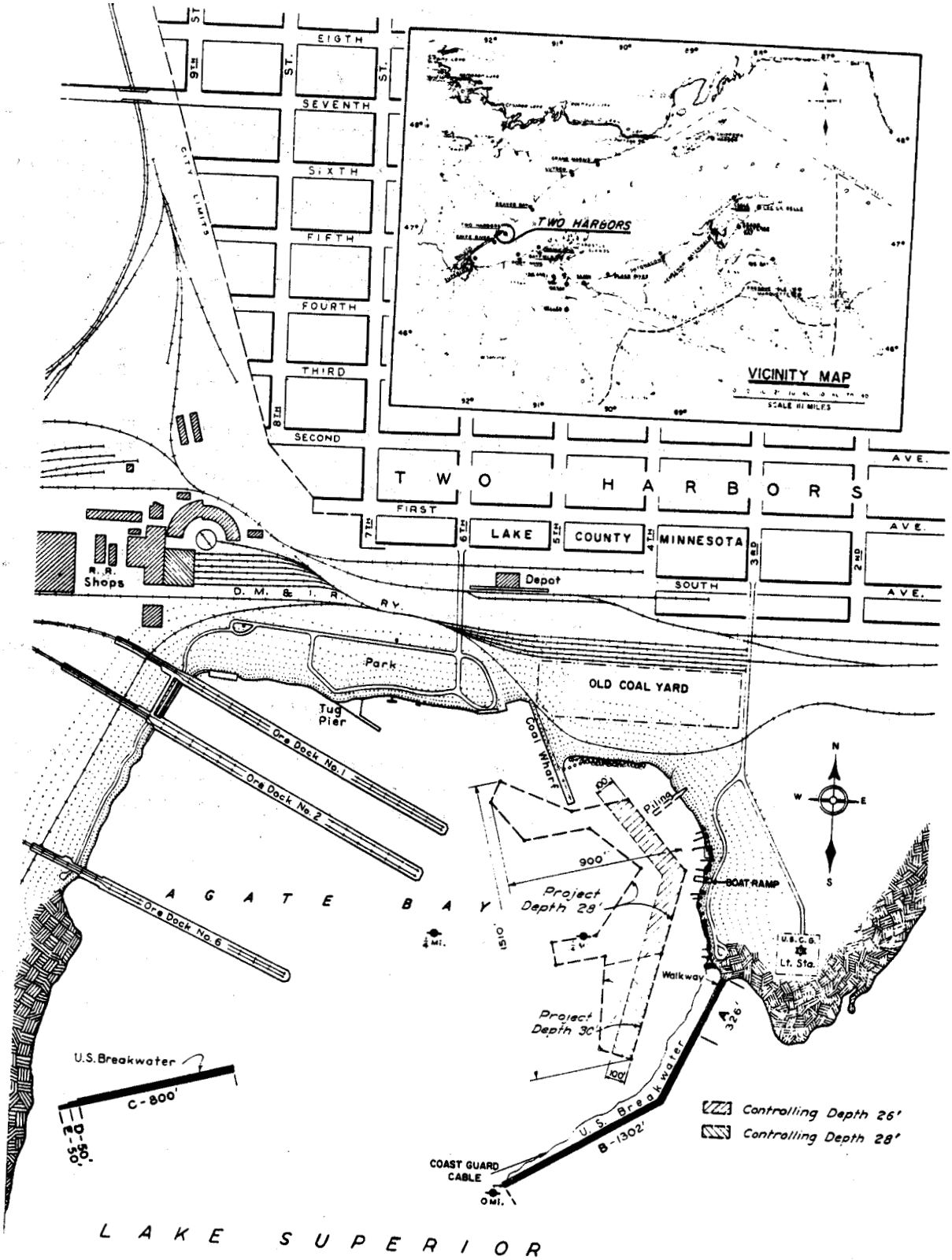


Figure 7: Two Harbors, Minnesota

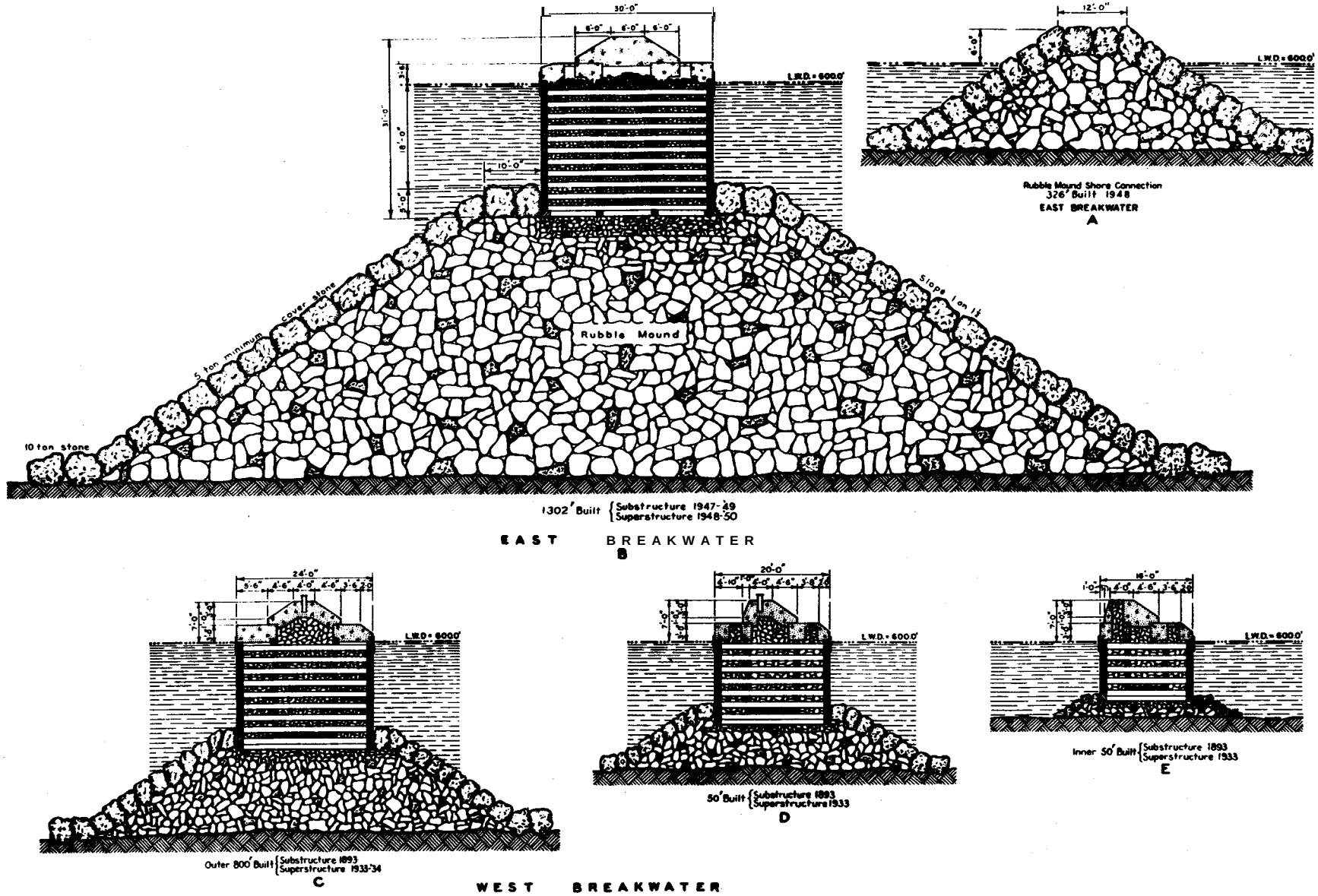


Figure 8. Typical structure cross sections, Two Harbors, Minnesota

Table 3

Knife River Harbor Breakwater

Knife River, Minnesota

Date(s)	Construction and Rehabilitation History
1957-1958	Construction of a 245-ft-long breakwater occurred at the site (Figure 9) during this time frame. The shoreward 215 ft of the structure was of rubble-mound construction, and the lakeward 30 ft was a stone-filled timber crib breakwater (Figure 10). The rubble-mound portion of the breakwater had a crest width of 8 ft and an el of +8 ft lwd. Side slopes of 1V:1.5H were constructed, and armor stone ranging from 3 to 5 tons was used. The timber crib structure was 30 ft wide with a crest el of +9 ft lwd. It was constructed on a stone mattress and had a timber deck. Rock was placed around the toe of the structure comprised of cover stone ranging from 1 to 5 tons. After construction it was noted that a design deficiency existed in that the breakwater did not effectively protect the harbor entrance from adverse wave conditions from northeasterly storms.
1974	A modification to the project authorized the construction of a 451-ft-long rubble-mound breakwater with four 62.8-ft diam steel sheet-pile cells (250 ft) at its head (Figure 9). Construction of the breakwater has not been initiated.
1986	Since the original breakwater was completed, it has sustained some localized damage which was repaired during routine maintenance. The structure is presently in good condition.

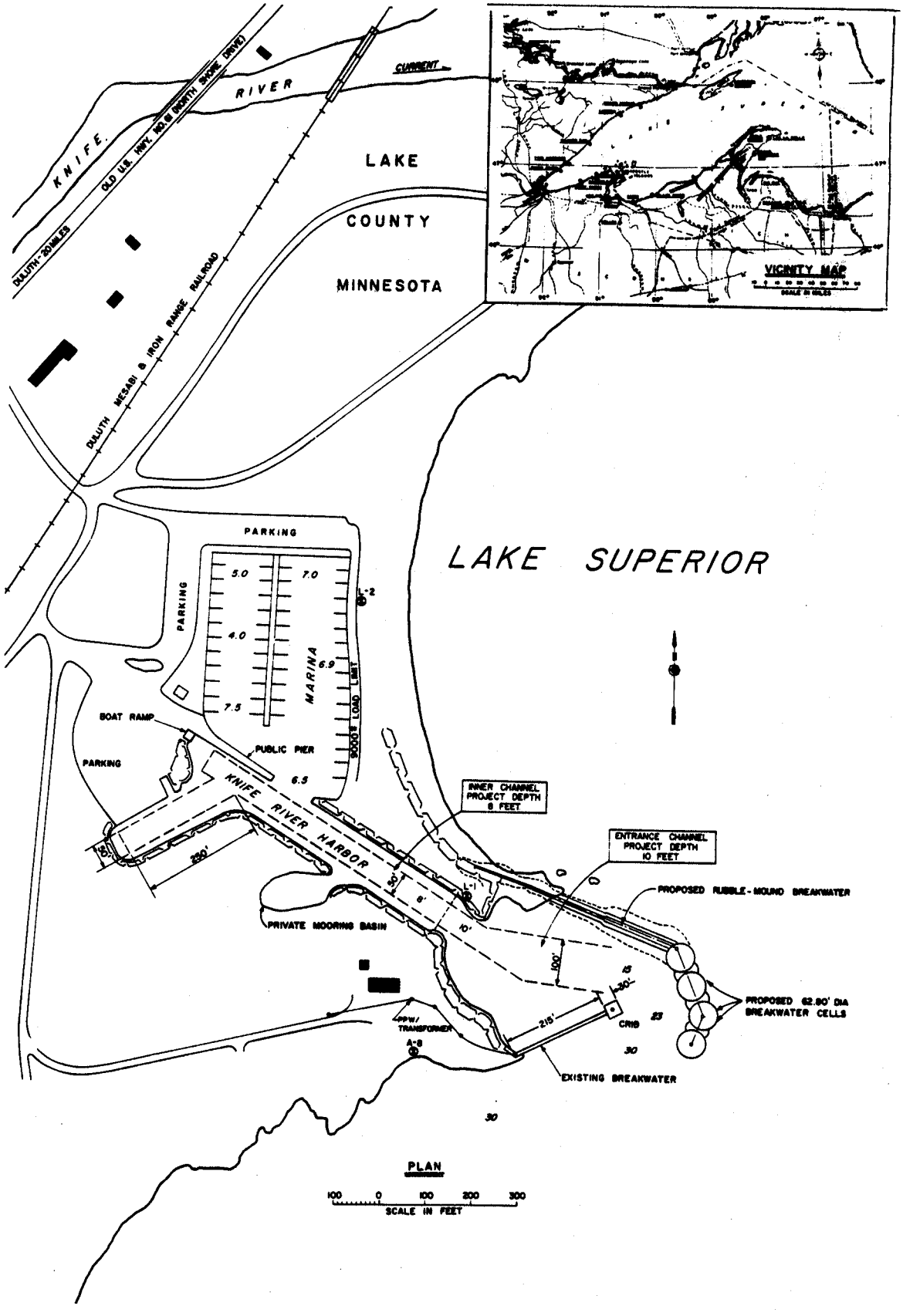
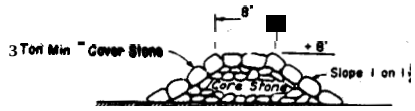
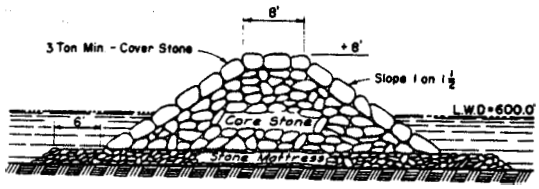


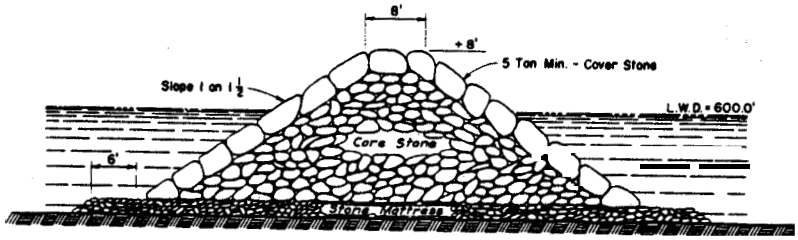
Figure 9. Knife River Harbor, Minnesota



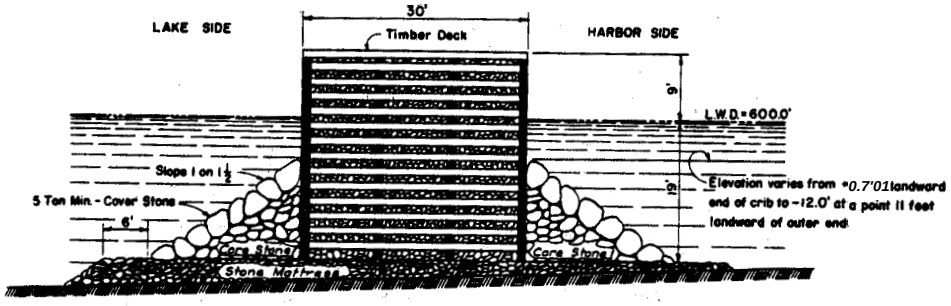
RUBBLE MOUNO
Landward End to LW 0 Shore Line
Built 1957-1958



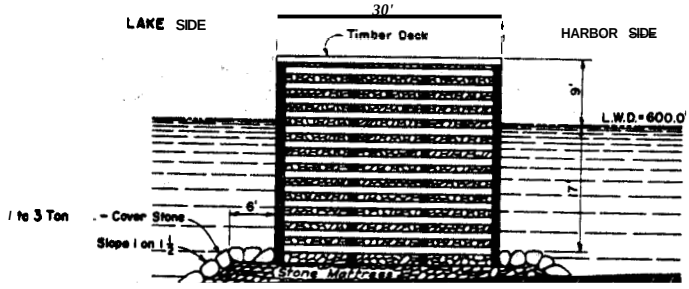
RUBBLE MOUNO
L.W.O. Shore Linr to -10 Contour
Built 1957-1958



RUBBLE MOUNO
-10 Contour to Landward End of Crib
Built 1957-1958



TIMBER CRIB
Landward 25'
Built 1957-1958



TIMBER CRIB
Lakeward 5'
Built 1957-1958

Figure 10. Typical structure cross sections, Knife River Harbor, Minnesota

Table 4

Duluth-Superior Harbor Structures

Duluth-Superior, Minnesota and Wisconsin

Date(s)	Construction and Rehabilitation History
1898-1900	The construction of two 1,720-ft-long entrance piers at Duluth Ship Canal (Figure 11) occurred during this period. These were timber crib structures filled with stone and timber (oak and pine) with a concrete superstructure (monolith blocks). The el of the superstructure ranged from +10 to +18 ft lwd with widths of 24 ft to 36 ft at the structure heads (Figure 12).
1904-1907	Construction of a 2,096-ft-long north pier and a 1,581-ft-long south pier progressed at Superior Entry (Figure 11). These structures were built with concrete. Crest widths ranged from 8 to 11 ft with els ranging from +10 to +16 ft lwd (Figure 12).
1908-1913	During this time, a 4,137-ft-long north breakwater and a 1,866-ft-long south breakwater were constructed (Figure 11) at Superior Entry. The pierheads and breakwater heads were timber cribs filled with stone and timber. Crest els were +10 ft lwd, and widths were 40 and 31 ft, respectively, for the pierheads and breakwater heads (Figure 12). The breakwater trunks were rubble-mound structures installed at el +8 ft lwd (Figure 12) with 1V:1.5H side slopes. Ten-ton armor stone was used. The shoreward ends consisted of concrete structures installed on rubble (Figure 12). Crest widths were 12 ft, and crest els were +8 ft lwd.
1933	A 530-ft-long rubble-mound shore connection was installed on the inner end of the north breakwater at Superior Entry. It consisted of an 8-ft crest width at an el of +8 ft lwd with 1-V:1.5-H side slopes.
1949	Thirty feet of the outer south pierhead at Duluth Ship Canal was rebuilt, and 406 ft of the south pier at Superior Entry was rebuilt. These consisted of steel sheet-pile walls and concrete (Figure 12). The pierhead at Duluth Ship Canal was built with a crest width of 14 ft at an el of +13 ft lwd. The pier at Superior Entry was 8 ft wide with an el of +10 ft lwd.
1956	Longitudinal cracks on the pierhead in the middle of the superstructures were repaired at Duluth Ship Canal. The repair consisted of horizontal tie bolts through each monolith and reinforcing bars drilled and grouted through the tunnel. After the bars were in place, the tunnel was filled with concrete. No separation of the monolith has occurred since then.
1957-1958	Twenty-six feet at the inner end of the south pierhead and 1,019 ft at the south pier at Superior Entry were rebuilt using steel sheet-pile walls and concrete (Figure 12).

(Continued)

Table 4 (Concluded)

Date(s)	Construction and Rehabilitation History
1960	A hydraulic model investigation (Wilson 1963) was conducted at Superior Entry to improve wave conditions in the navigation channel and at the ore docks located opposite the entry. Proposed plans involved detached breakwaters lakeward of the existing entrance. Improvements were never constructed at the site.
1977-1978	The concrete superstructures of the north and south piers and the substructures at Duluth Ship Canal were inspected. The timber cribs, riprap, and armor protection were determined to be, generally, in good condition. Small gaps were noted along the joints of the cribs, but the timbers were still firm, and no warping was noted. Some cracks were noted in the monolith blocks, but there was no misalignment or settlement; and the joints were all tight.
1984	An inspection of the piers at Duluth Ship Canal was conducted. The north pier was in need of work both above and below the surface, and the south pier was reported in very good condition. An inspection of the Superior Entry inner piers indicated that the structures were in fair condition. In general, the structures needed maintenance, and repairs were done.
1986	In general, very little maintenance has been needed since construction of the project. Minor patching of spalling concrete has been attempted with generally poor results. The structures overall are presently in fair condition.

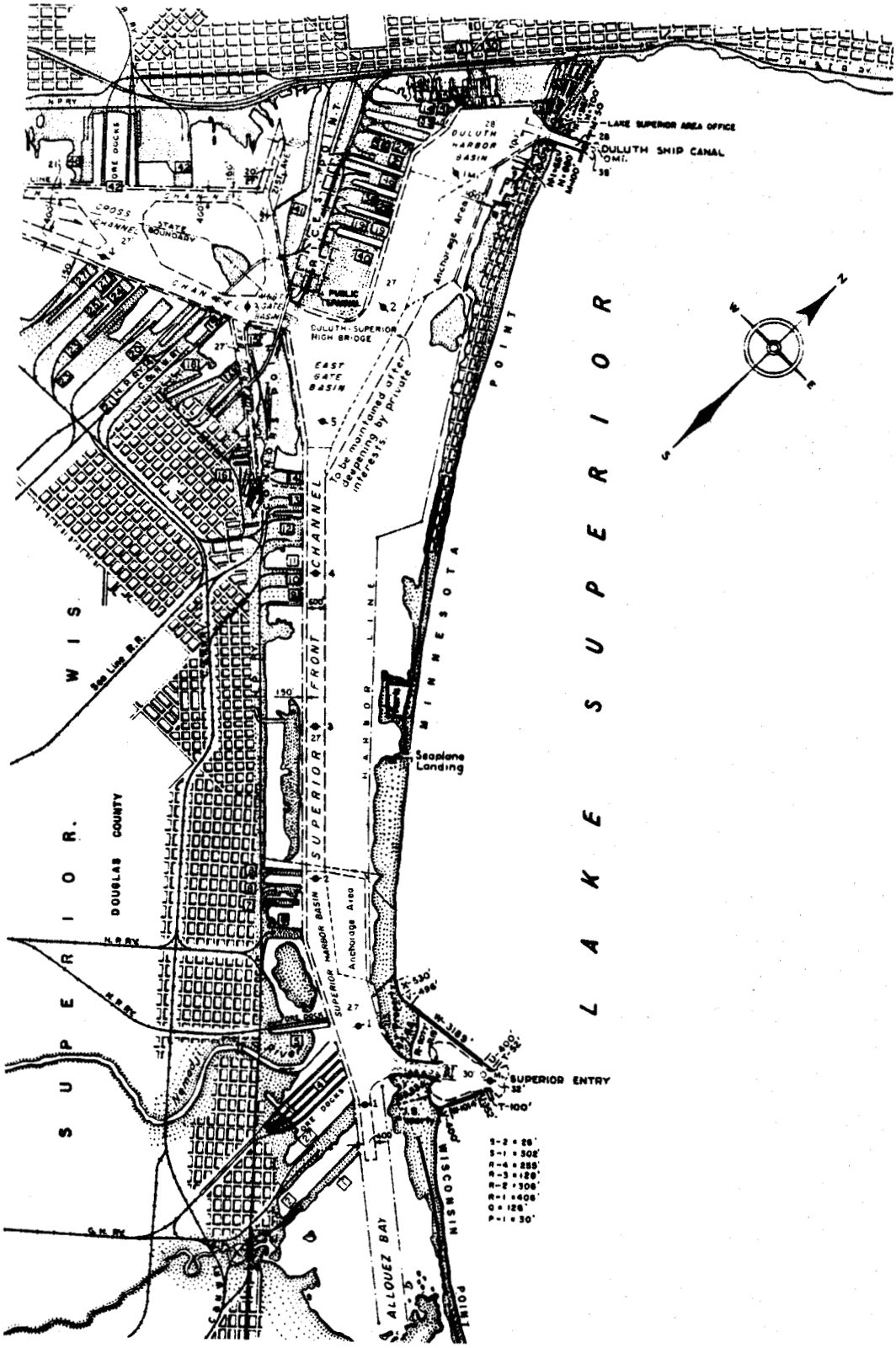


Figure 11. Duluth-Superior, Minnesota and Wisconsin

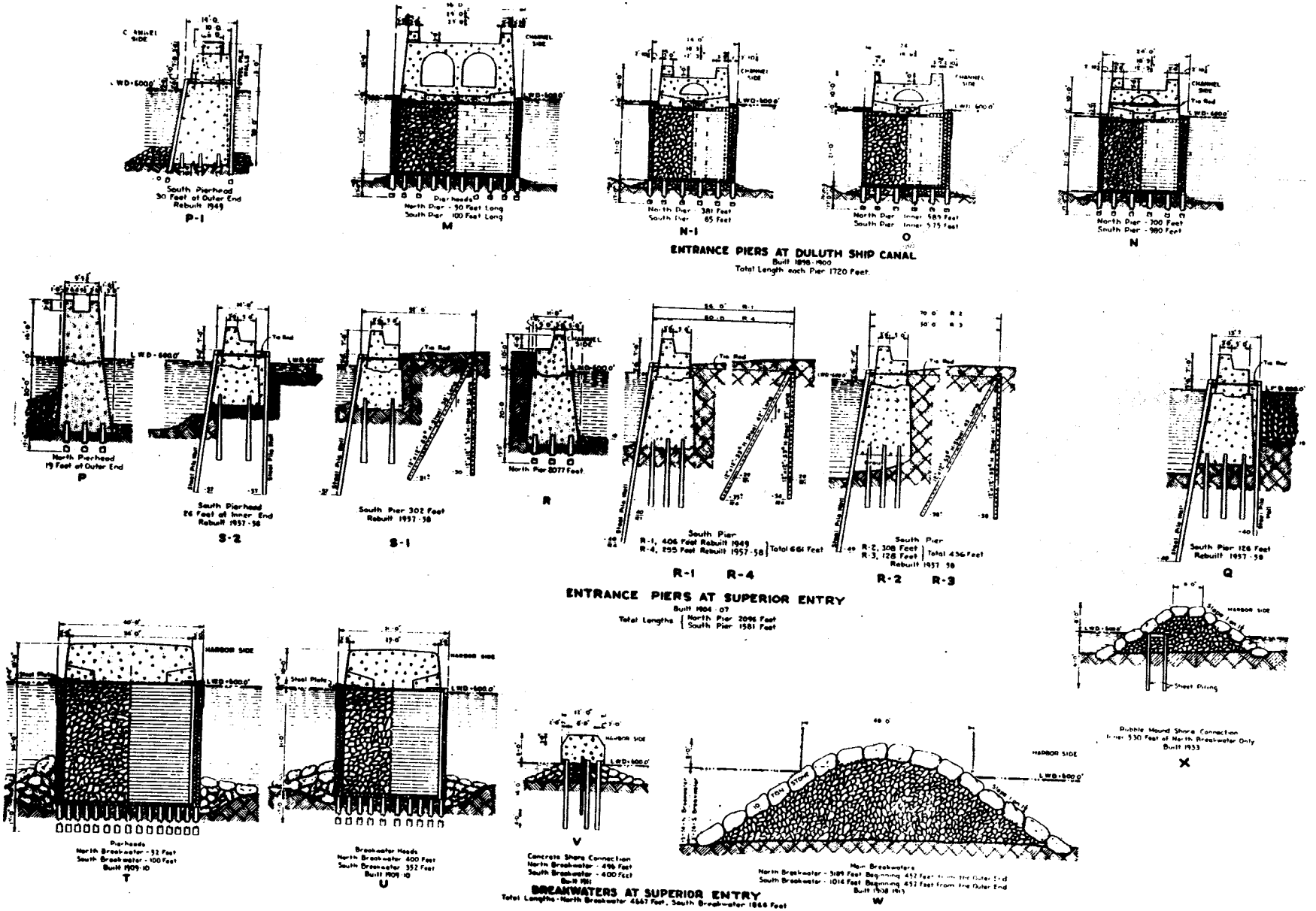


Figure 12. Typical pier cross sections, Duluth-Superior, Minnesota and Wisconsin

Table 5

Port Wine: Harbor Piers

Port Wing, Wisconsin

Date(s)	Construction and Rehabilitation History
1903–1904	The construction of an 800-ft-long east pier and a 45-ft-long pile revetment progressed at the site (Figure 13).
1906	The outer 555 ft of the west pier (Figure 13, Section A) was constructed. The structure consisted of wood piles filled with wood slabs and capped with stone. It was 11 ft wide and installed at an el of +5.5 ft lwd.
1917	The inner 224 ft of the west pier was constructed. The cross section of the structure was the same as the outer portion built in 1906.
1946	The outer portion of the west pier (45.6 ft long) was rebuilt (Figures 13 and 14, Section B). Steel sheetpiling and stone were used to increase the width of the structure to 18.7 ft. Large stone was used to cap the structure. The crest el was +5 ft lwd.
1949–1950	The east pier and pile revetment were rebuilt. The east pier consisted of wood piles filled with stone and capped with a concrete and stone superstructure. The crest el of the structure was +5.5 ft lwd with a 19.75-ft width, and the length was decreased to 446.5 ft. Stone was placed on the lakeside of the pier (Figure 14, Section C). The pile revetment consisted of woodpiling filled with sand and capped with concrete. It was increased to 388 ft in length. The el was +4.0 ft lwd, and stone was placed on the channel side (Figure 14, Section D).
1961	Steel sheetpiling was placed on the shoreward end of the west pier for a distance of 192.4 ft (Figures 13 and 14, Section E). The structure was 1.0 ft wide at an el of +5.5 ft lwd. A rock berm was installed on each side of the structure (Figure 14, Section E). Steel sheetpiling was also placed on the channel side of the west pier for a distance of 779 ft (Figures 13 and 14, Section A).
1986	The structures presently are in good condition.

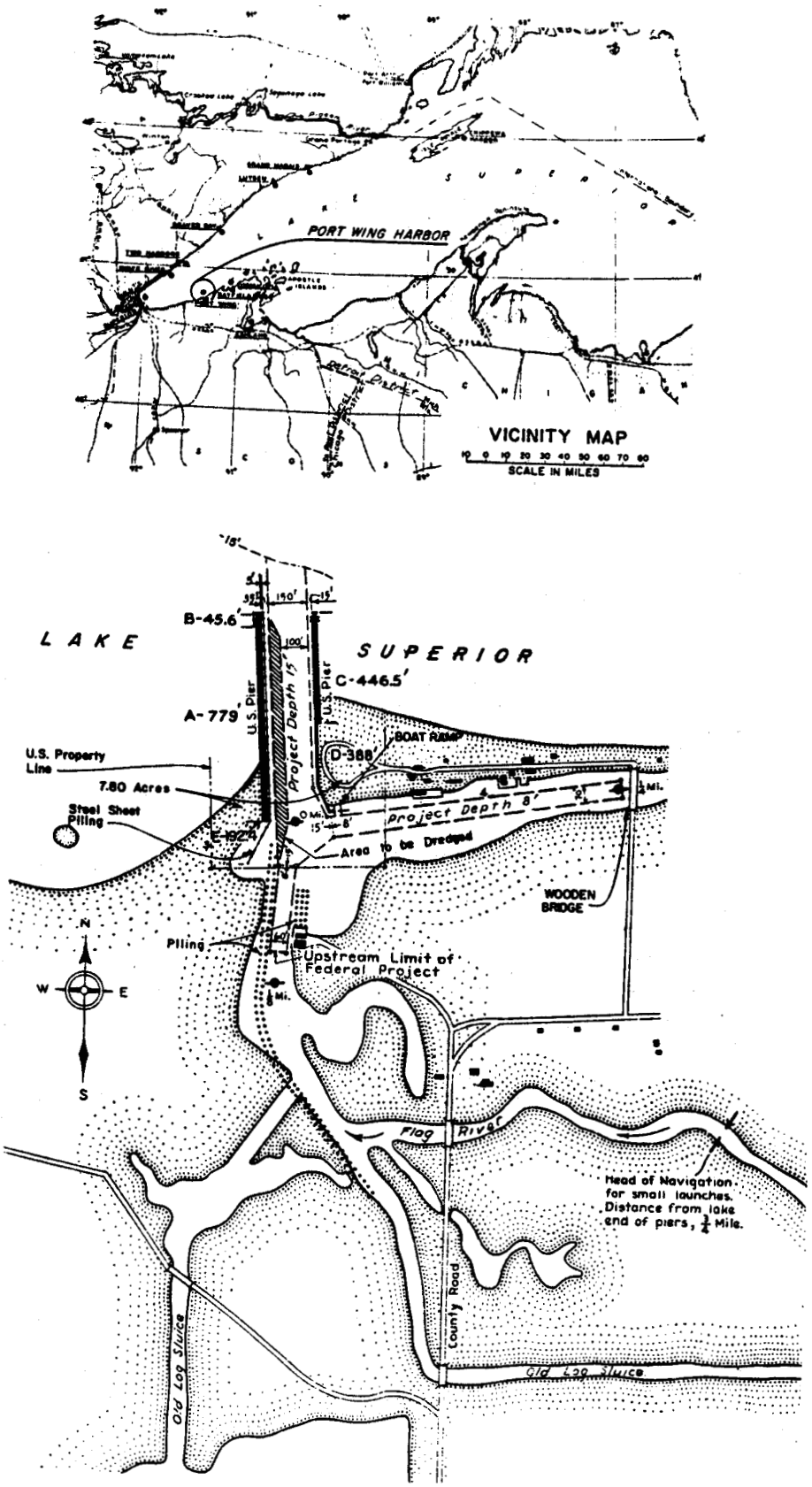
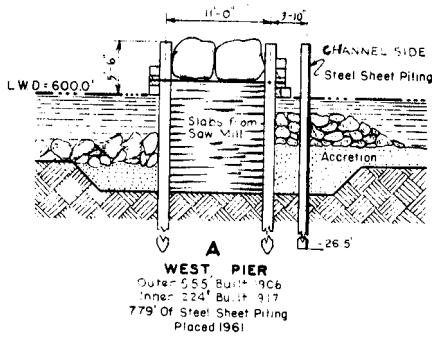
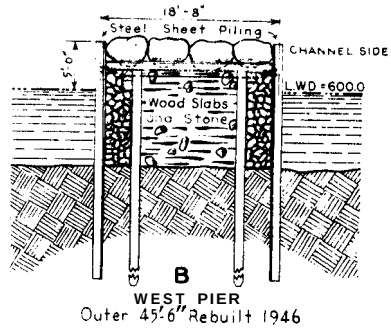
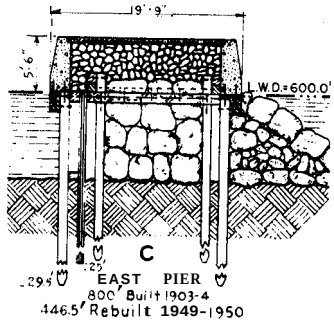
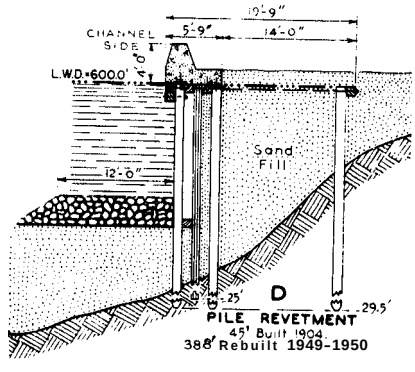


Figure 13. Port Wing Harbor, Wisconsin









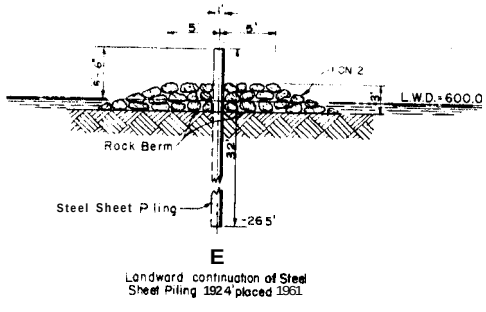


Figure 14. Typical structure cross sections, Port Wing Harbor, Wisconsin

Table 6

Cornucopia Harbor Piers

Cornucopia, Wisconsin

Date(s)	Construction and Rehabilitation History
1957	Construction of a 938-ft-long east pier and a 530-ft-long west pier was completed at the site (Figure 15). The shoreward 370 ft and 372 ft of the west and east piers, respectively (Figures 15 and 16, Section D), were constructed with woodpiling and filled with stone. Steel sheetpiling was installed also on the channel side at an el of +8 ft lwd. The remaining 160 ft of the west pier, and the next 286 ft of the east pier (Figures 15 and 16, Sections B and C) were constructed of woodpiling with sand and stone fill. Steel sheet-piling was installed on each side of the structure at a +8 ft el lwd. Stone was grouted in place to cap the structure. The west pier was 15 ft wide, and the east pier ranged from 17 to 45 ft in width. The next 100 ft of the east pier was constructed of steel sheetpiling with sand and rock fill (Figures 15 and 16, Section E). This structure was 24 ft wide with a crest el of +8 ft lwd. The outer 180 ft of the east pier was a cellular sheet-pile structure (Figures 15 and 16, Section F). The cells were filled with dredged sand or gravel and capped with 2 ft of rocks filled with grout. The diameter of the cells was 30.55 ft, and the crest el was +8 ft lwd. Rock berms were placed at the toe of the structure on both sides.
1986	No records of repair to the structure have been noted, and the piers presently'are in good condition.

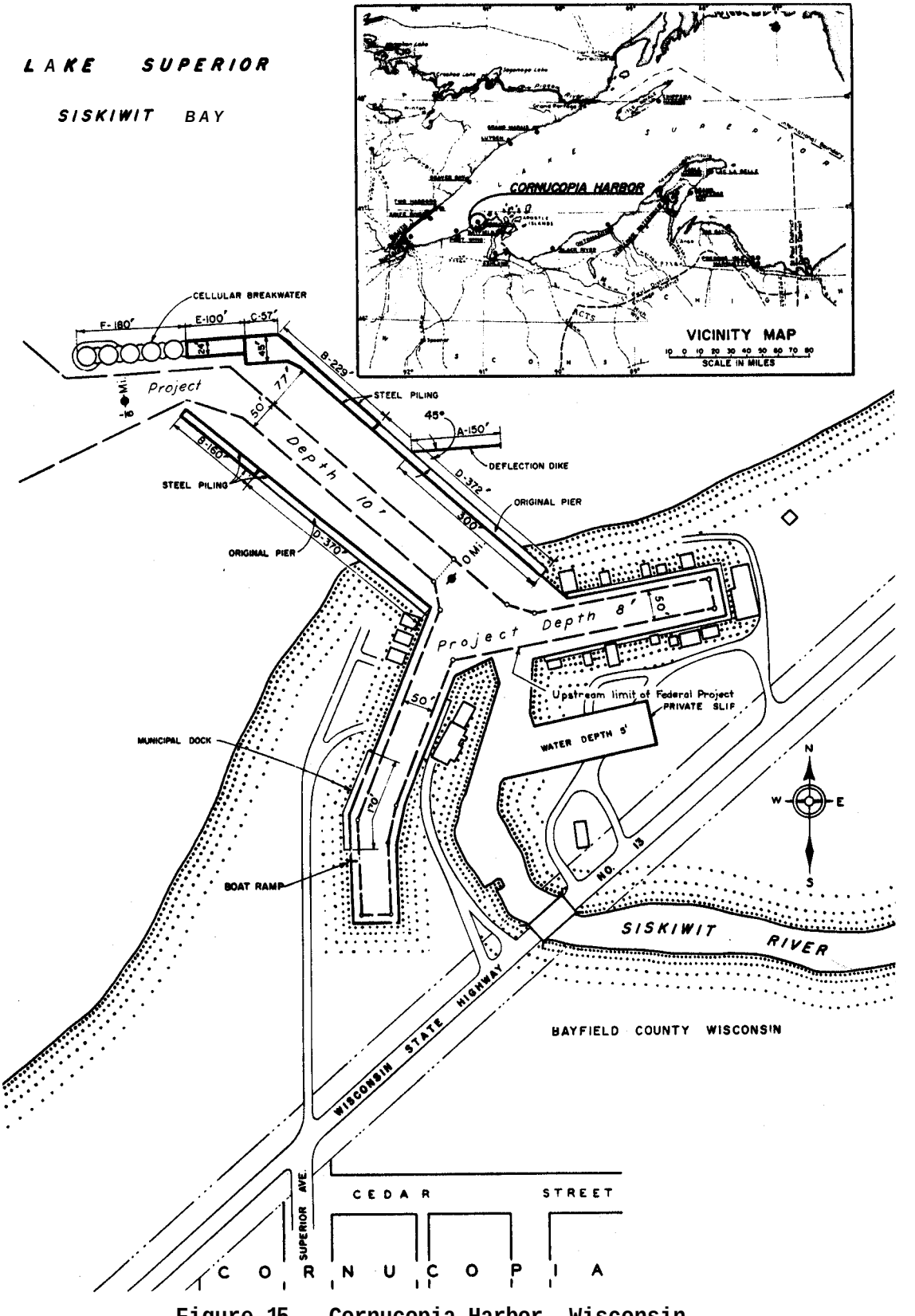


Figure 15. Cornucopia Harbor, Wisconsin

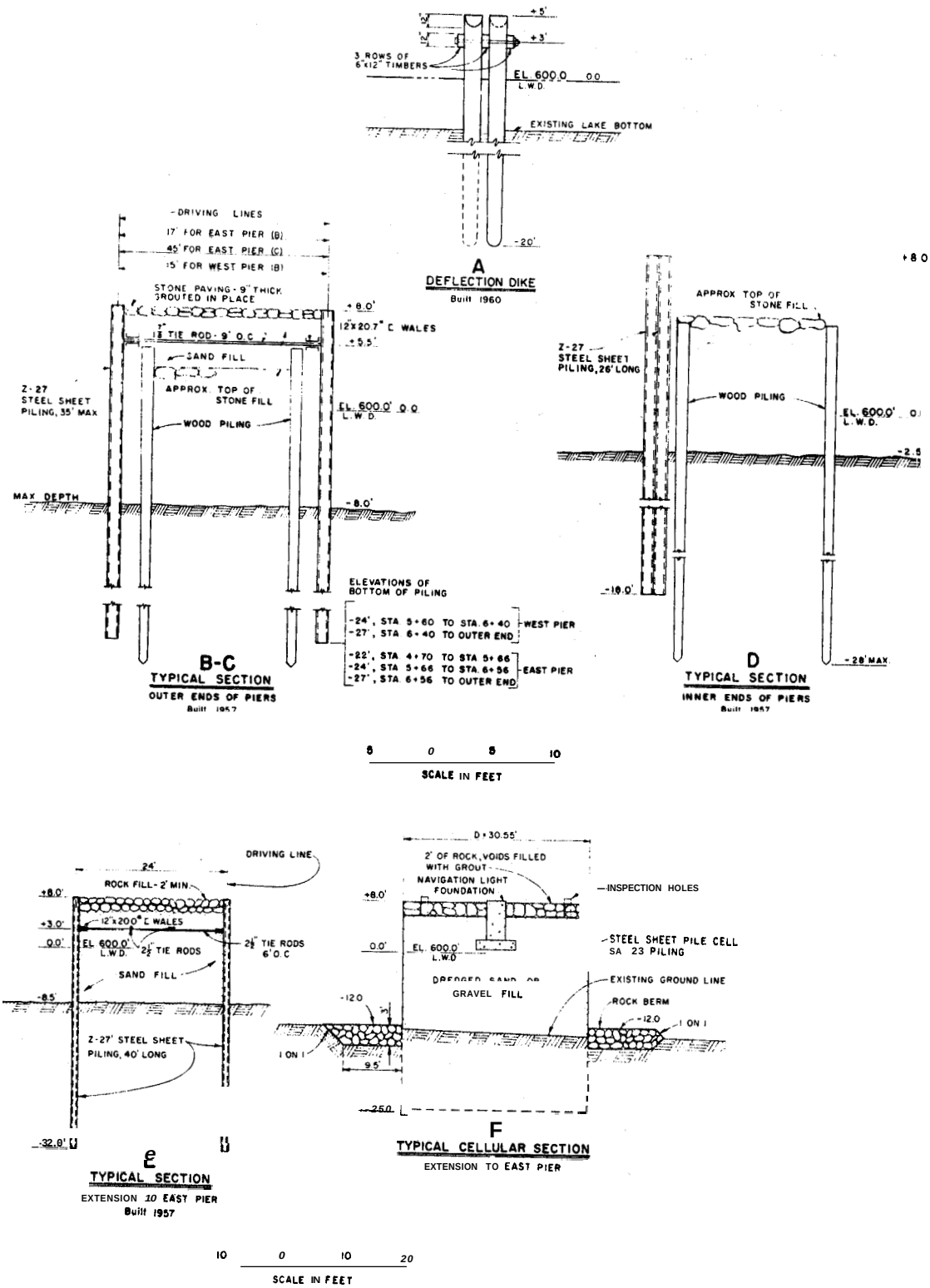


Figure 16. Typical structure cross sections, Cornucopia Harbor, Wisconsin

Table 7

Bavfield Harbor Structures

Bayfield Harbor, Wisconsin

Date(s)	Construction and Rehabilitation History
1936	A 465-ft-long pier (Figure 17, Section A) was constructed by the State of Wisconsin. The pier was a rock-filled timber crib structure that was 24 ft wide and had a crest el of +4 ft lwd (Figure 18, Section A).
1941	A 200-ft-long city pier ell and a 459-ft-long city breakwater pier (Figure 17, Section B) were constructed by the State of Wisconsin, The structures had the same cross sections as the pier built in 1936.
1960	A 103-ft-long extension of the city pier ell and a 139-ft-long extension of the city breakwater pier were completed by the Corps. The extensions were of cellular sheet-pile construction. The cell diameters were 30.55 ft in width and had a +6 ft lwd crest el. They were sand filled with a grout-filled stone cap. Toe protection was provided on the lakeward side of the north extension only (Figures 17 and 18, Section C). The Corps also built a parapet wall totaling 843 ft in length on the existing piers. The crest el of the parapet was +6 ft lwd.
1986	The structures presently are in good condition.

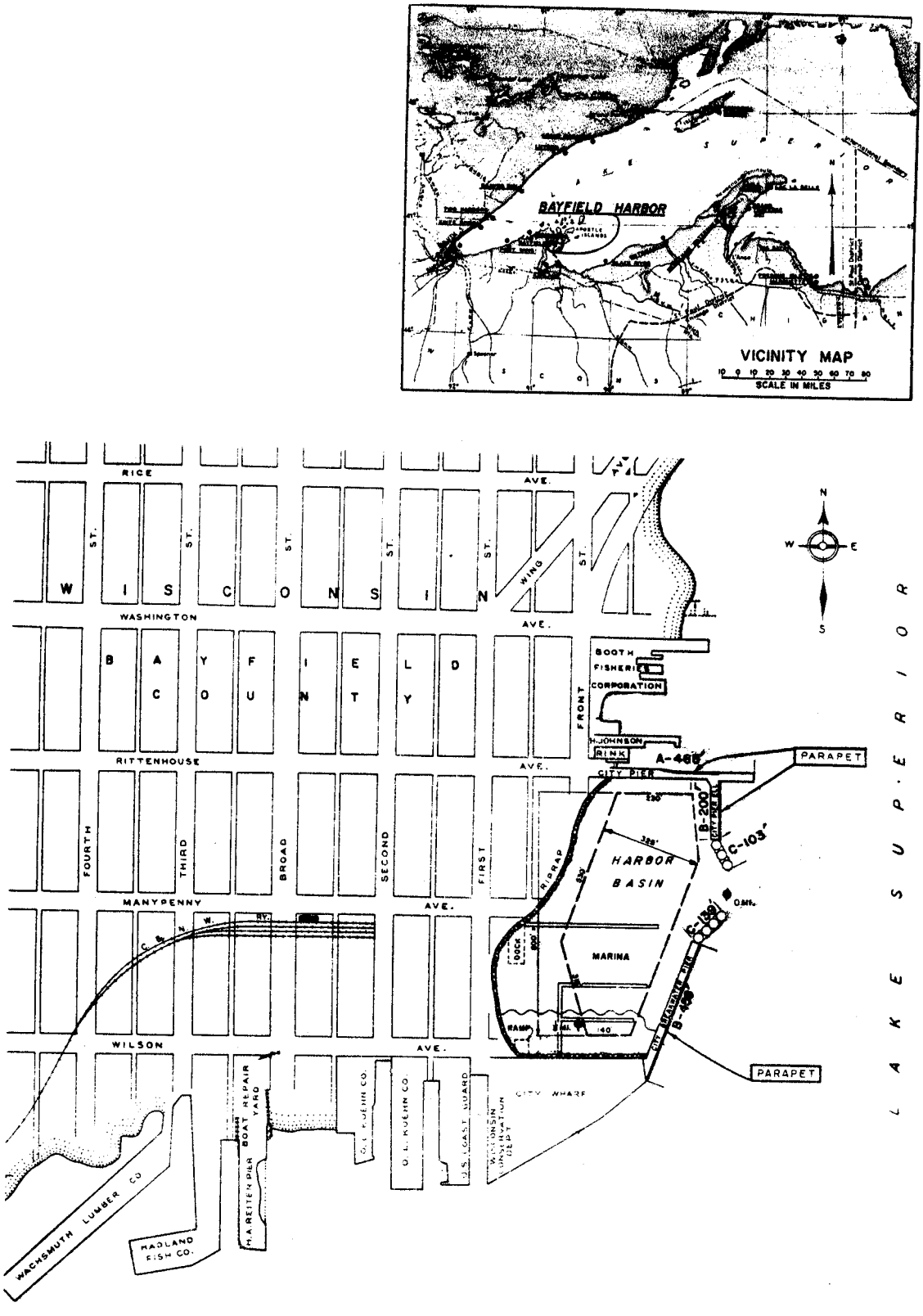
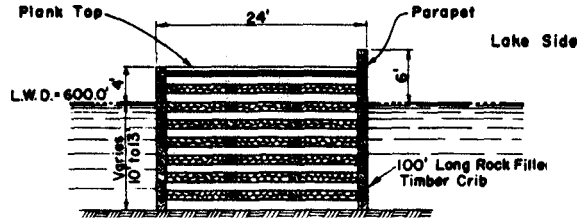


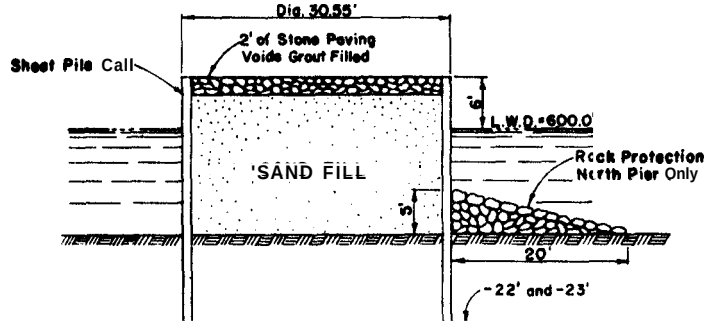
Figure 17. Bayfield Harbor, Wisconsin



A and B

A. City pier 465' long built 1936 by W.P.A.
184' of parapet added 1960

B. City Breakwater and City Pirr Ell built 1941
Superstructure rebuilt and parapet oddrd 1960



C

Built 1960

Figure 18. Typical structure cross sections, Bayfield Harbor, Wisconsin

Table 8

La Pointe Harbor Breakwater

Madeline Island, Wisconsin

Date(s)	Construction and Rehabilitation History
1967	A 200-ft-long extension of an existing rock-filled timber crib breakwater was completed by the Corps (Figure 19). The existing structure was 37.3 ft wide with a crest el of +4 ft lwd. It was constructed by local interests (Figures 19 and 20, Section A). The initial 74 ft of the extension was built with steel sheetpiling that was sand filled and capped with stone (Figures 19 and 20, Section B). It was 25 ft wide with a crest el of +7 ft lwd on the lakeside and +4 ft lwd on the harbor side. The lakeward 126-ft length of extension was a cellular sheet-pile structure with cell diameters of 20.36 ft. They were sand filled and had stone caps (Figures 19 and 20, Section C). The crest el of the sheet pile was +7 ft lwd on the lakeside and ranged from +4 to +7 ft lwd on the harbor side. Riprap was placed along the toe of the cellular structure.
1986	No repairs to the structure have been noted, and it is presently in good condition.

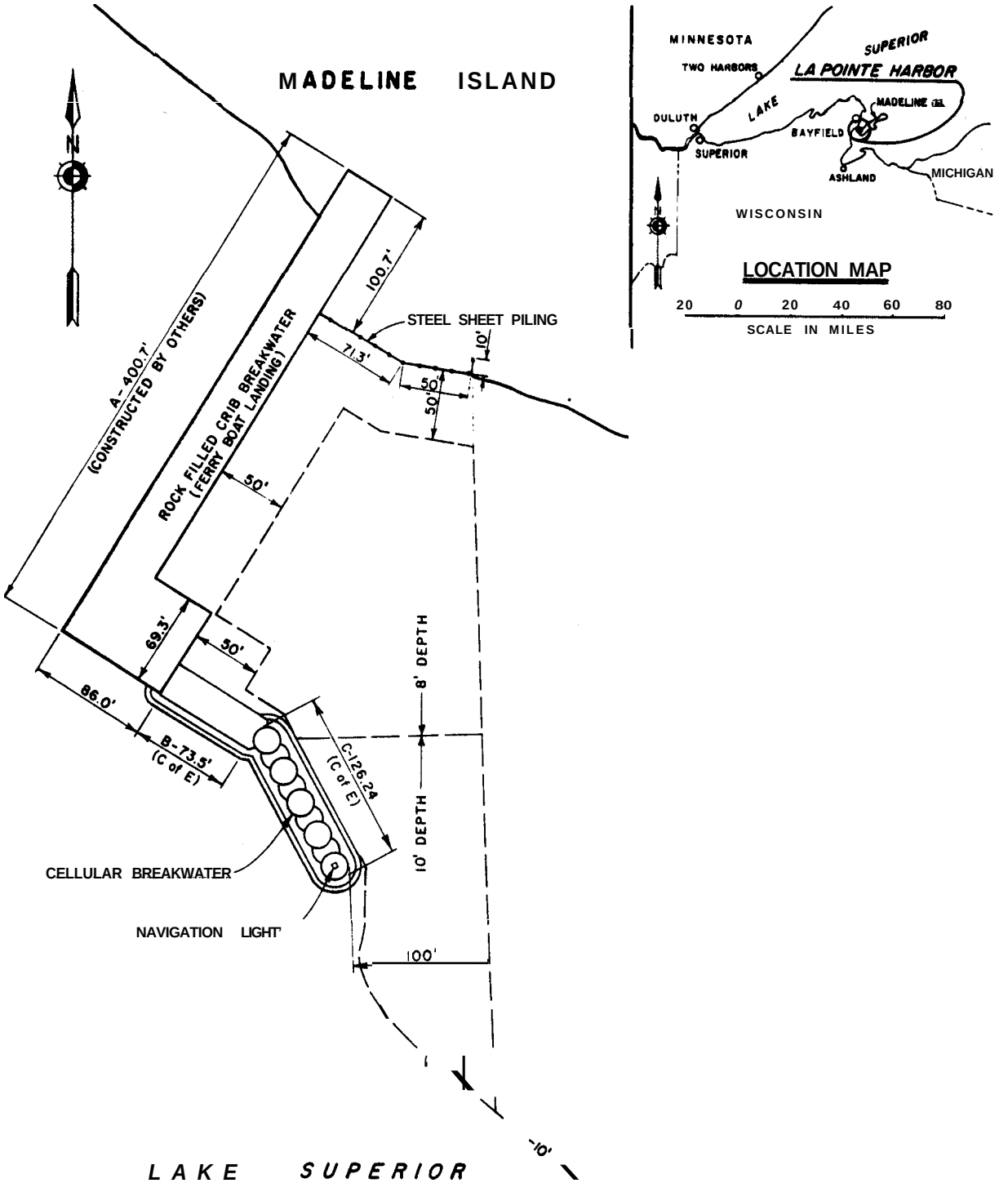
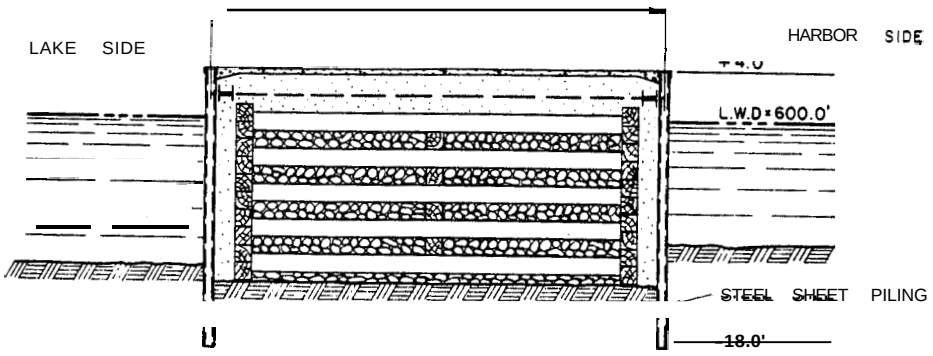


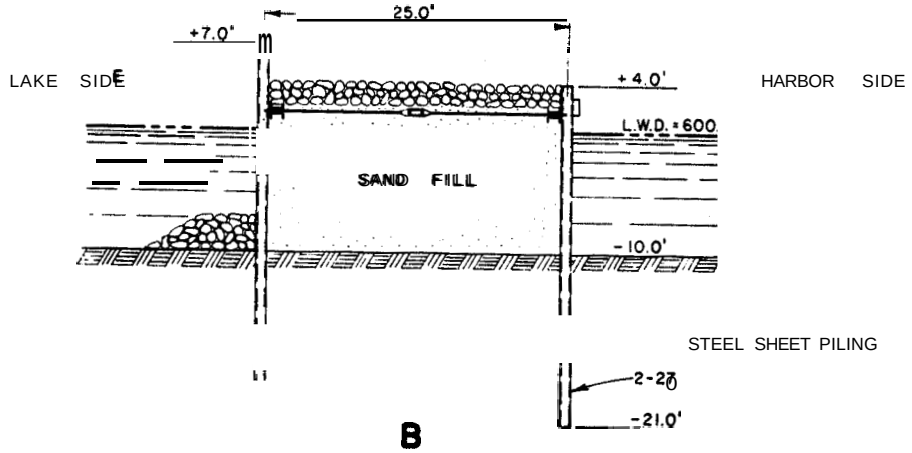
Figure 19. La Pointe Harbor, Wisconsin



A

BREAKWATER

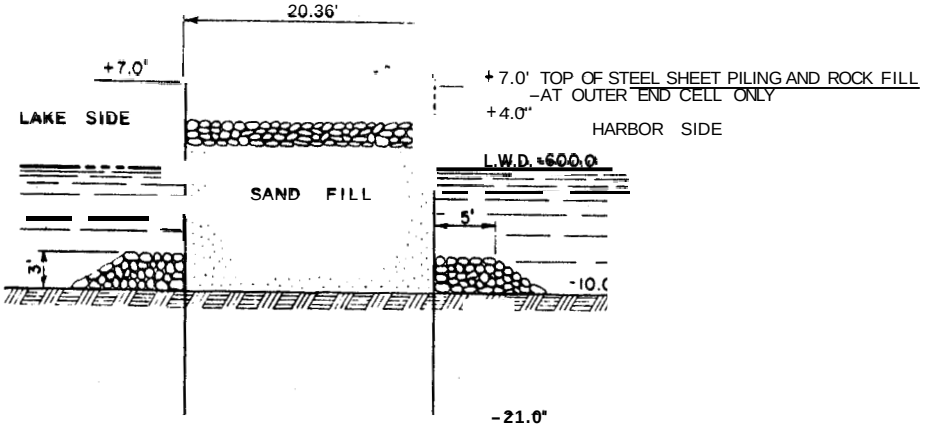
TIMBER CRIB 400.7'
(COMPLETED BY OTHERS)



B

BREAKWATER

STEEL SHEET PILING 73.5'
(CORPS OF ENGINEERS)



C

BREAKWATER

CELLULAR 126.24'
(CORPS OF ENGINEERS)

Figure 20. Typical breakwater cross sections, La Pointe, Wisconsin

Table 9

Ashland Harbor Breakwater

Ashland, Wisconsin

Date(s)	Construction and Rehabilitation History
1889-1894	Construction of a 7,363-ft-long timber crib breakwater progressed at the site (Figures 21 and 22, Section C) during this time. The structure was filled with timber slabs and capped with stone, It had a crest width ranging from 20 to 28 ft and was installed at el +7 ft lwd.
1908-1910	Stone reinforcement was installed on both sides of the structure (Figure 22, Section C) on a slope of 1V:1.5H.
1911	A timber crib pierhead was constructed. The structure was stone and timber filled, 32 ft wide, and 48 ft long. Riprap toe protection was included (Figures 21 and 22, Section A).
1912-1913	A 589-ft-long rubble-mound breakwater was built during this period. The structure connected the pierhead to the original breakwater (Figure 21, Section B). It had a +7 ft lwd crest el with a 10-ft-width (Figure 22, Section B). Side slopes were approximately 1V:1H.
1913-1914	A concrete and stone cap (superstructure) was installed on the pierhead. The el of the structure was now +6.75 ft lwd.
1986	Only routine maintenance has been performed, and the structure presently is in fair condition.

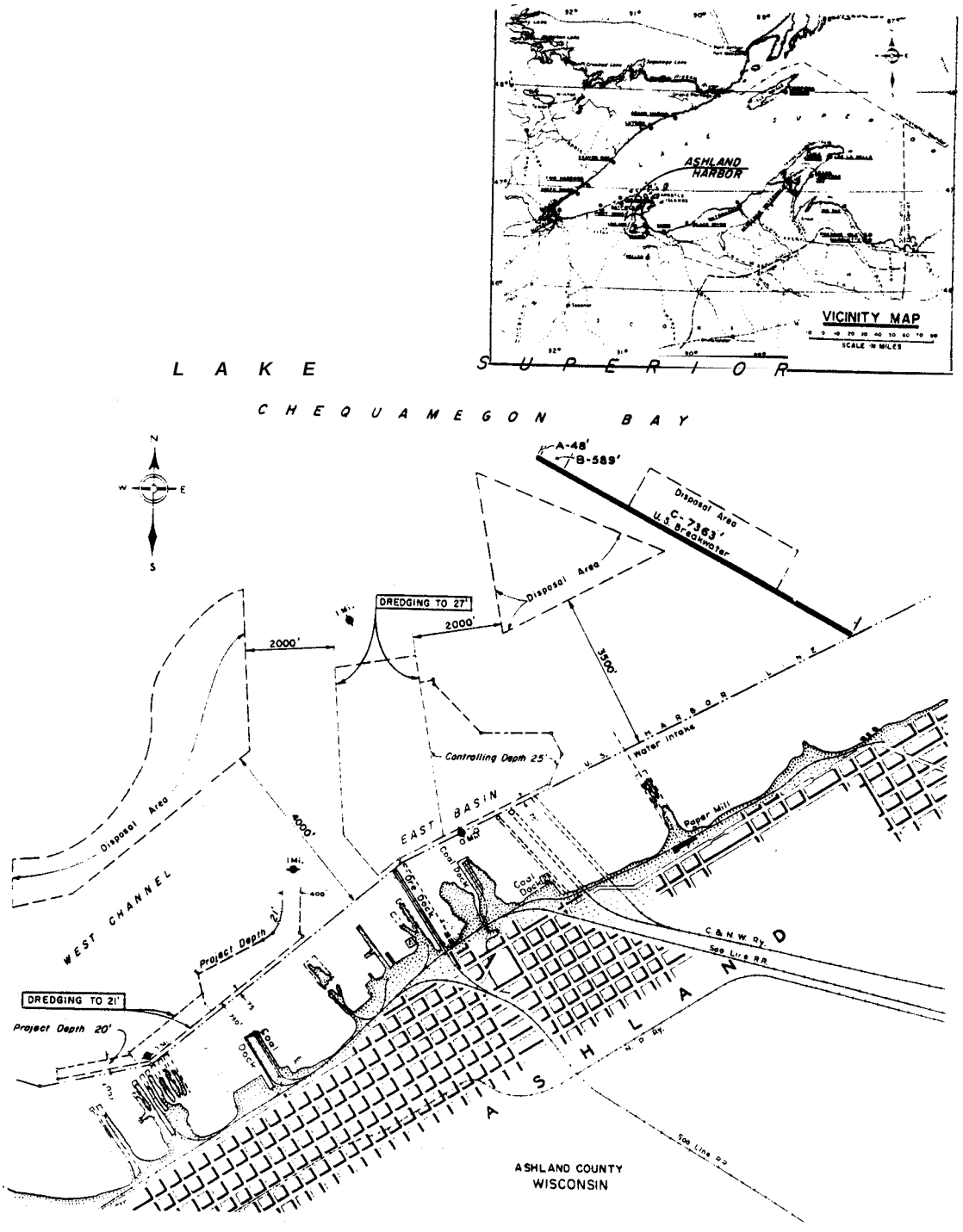
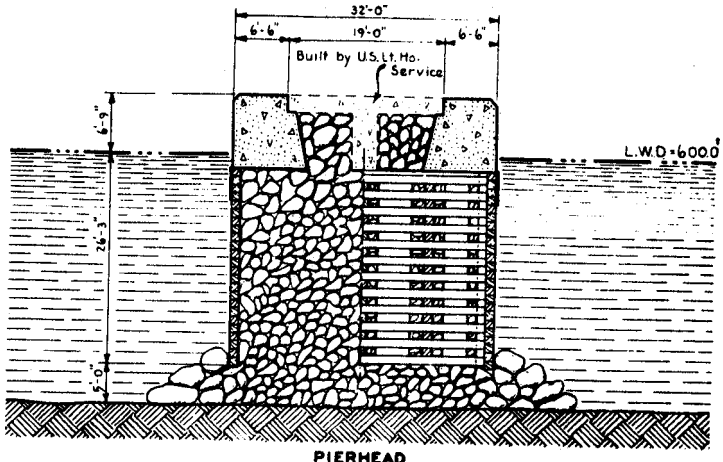


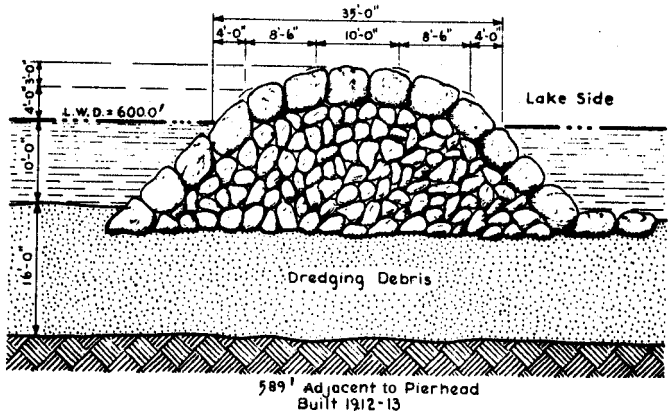
Figure 21. Ashland Harbor, Wisconsin



PIERHEAD

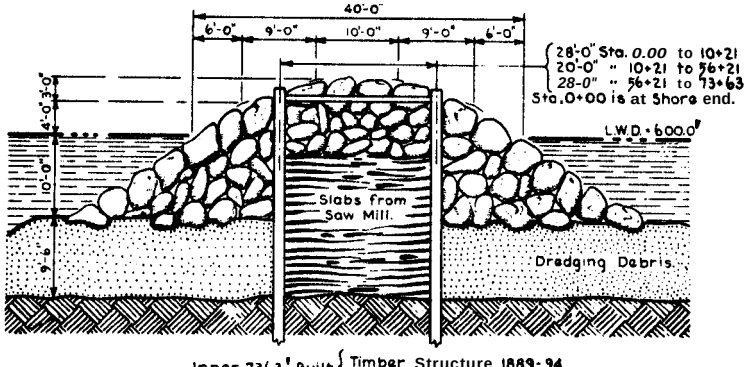
Outer 48' Built { Substructure 1911 / Superstructure 1913-14

A



589' Adjacent to Pierhead
Built 1912-13

B



Inner 7363' Built { Timber Structure 1889-94 / Rubble Reinforcement 1908-10.

BREAKWATER

C

Figure 22. Typical structure cross sections, Ashland Harbor, Wisconsin

Table 10

Saxon Harbor Breakwaters

Saxon, Wisconsin

Date(s)	Construction and Rehabilitation History
1965	Construction of a 417-ft-long west breakwater and a 616-ft-long east breakwater was completed at the site (Figure 23). The shoreward 335 ft of the east breakwater was of rubble-mound construction. The crest el was +8 ft lwd with an 8-ft width, and side slopes were 1V:1.5H (Figure 24, Section A). Armor stone was approximately 6 ft thick. The shoreward 381.5 ft of the west breakwater was constructed of steel sheetpiling with rock toe protection (Figure 24, Section B). The crest el was +8 ft lwd. The lakeward ends of both structures were cellular sheet pile (Figures 23 and 24, Section C). Cells with diameters of 35.65 ft were used. They were filled with excavation fill and capped with stone (voids filled with concrete). The crest el of the cells was +8 ft lwd, and toe protection was included.
1983	An inspection made of the site indicated minor cracking of the cap of the innermost east breakwater cell. The cap of the outermost east breakwater cell was also noted cracking with a void in the center of the cap. In addition, the cap had settled as much as 8 in. in some areas.
1986	The structures have undergone only routine maintenance and presently are in good condition.

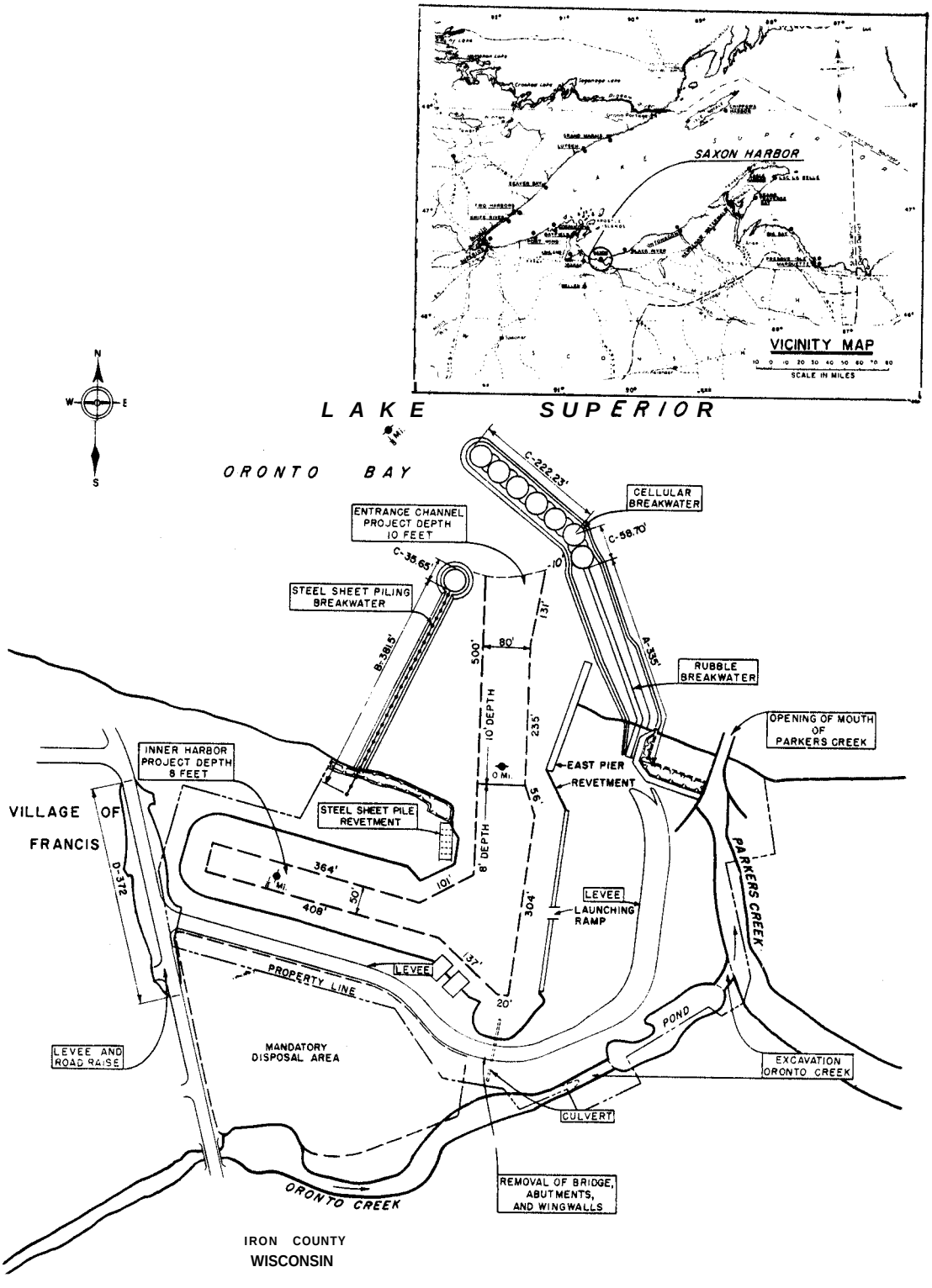


Figure 23. Saxon Harbor, Wisconsin

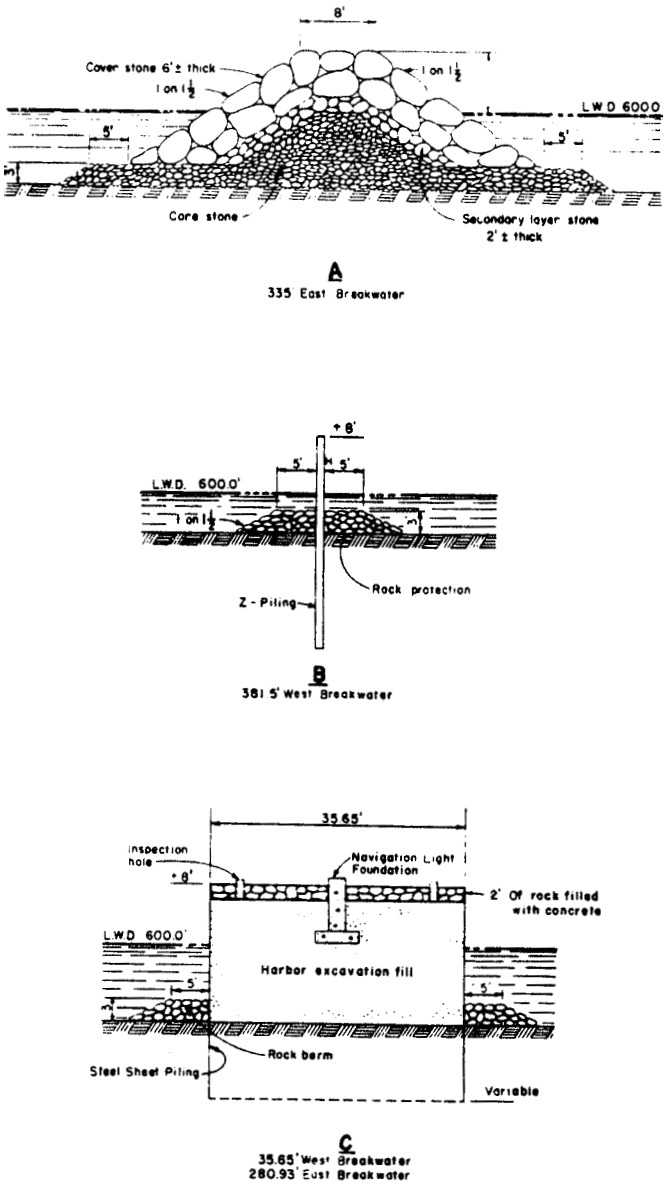


Figure *24.* **Typical breakwater cross sections, Saxon Harbor, Wisconsin**

Table 11

Black River Harbor Breakwaters

Gogebic County, Michigan

Date(s)	Construction and Rehabilitation History
1957	The construction of an 825-ft-long east breakwater and a 555-ft-long west breakwater was completed at the site (Figure 25). The breakwaters were of rubble-mound construction (Figure 26) with crest els of +7 ft lwd and crest widths of 8 ft. Side slopes were 1V:1.5H, and 3-ton minimum armor stone was used.
1983	An inspection made of the structures revealed that both breakwaters were in good condition with the exception of several areas on each structure that needed additional core and cover stone.
1986	Since construction, the breakwaters have been repaired during routine maintenance operations. They presently are in good condition. An aerial view of Black River Harbor breakwaters is shown in Figure 27.

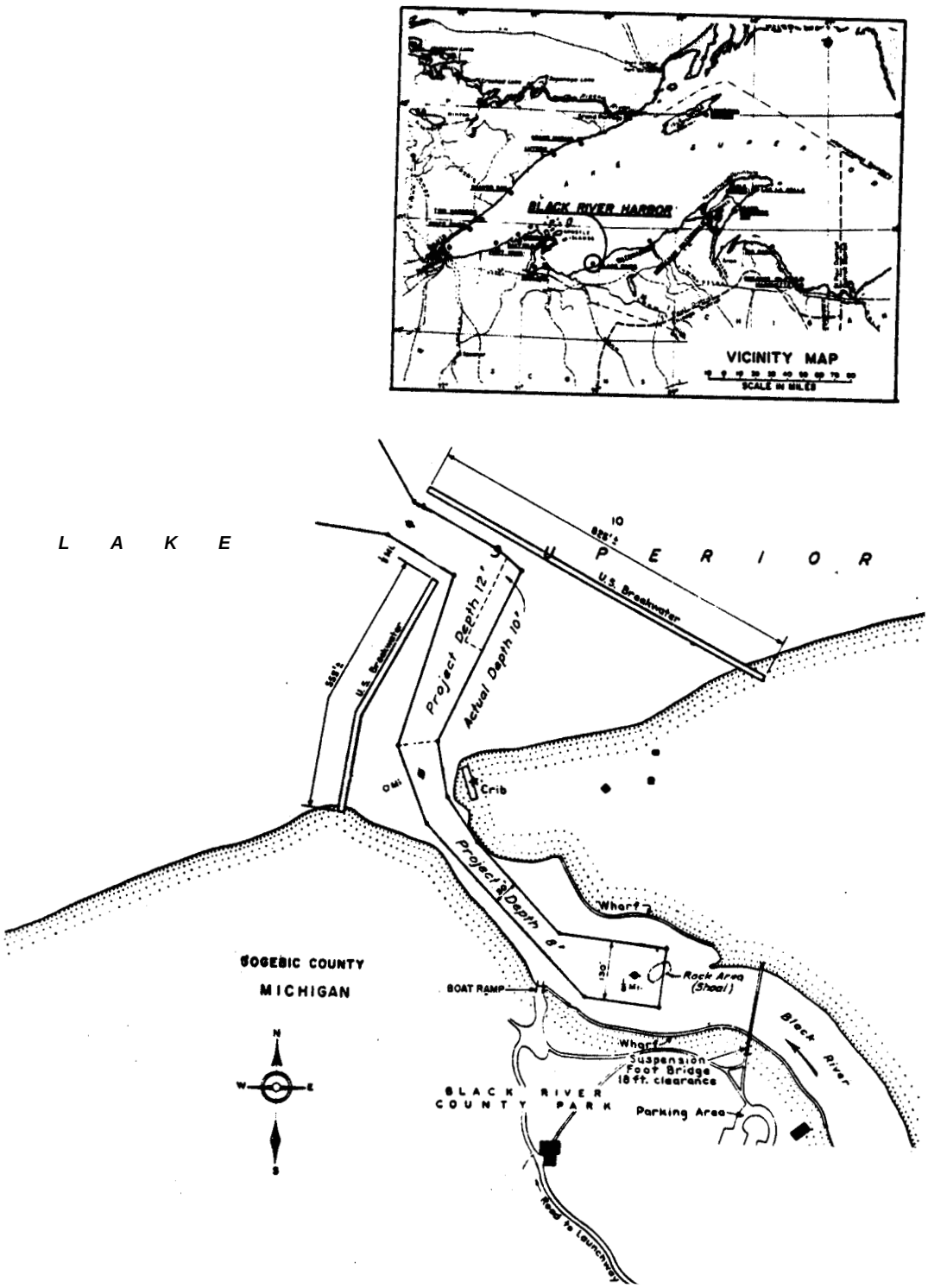
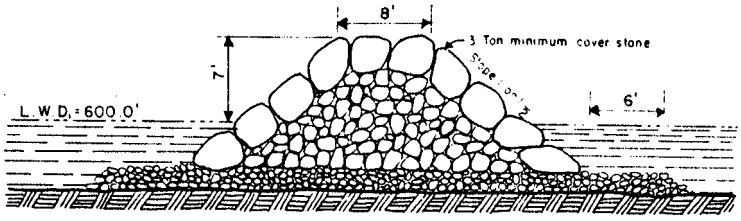
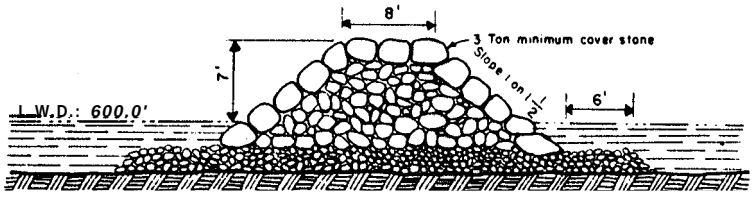


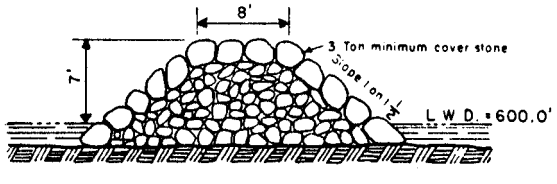
Figure 25. Black River Harbor, Michigan



Lokeword End to – 5 Ft. Contour



– 5Ft. Contour to + 2 Ft. Contour



+ 2 Ft. Contour to Londword End

RUBBLE MOUND - BUILT 1957

EAST AND WEST BREAKWATERS

Total Lengths { East Breakwater - 825 Ft. ±
West Breakwater - 555 Ft ±

Figure 26. Typical breakwater cross sections, Black River Harbor, Michigan

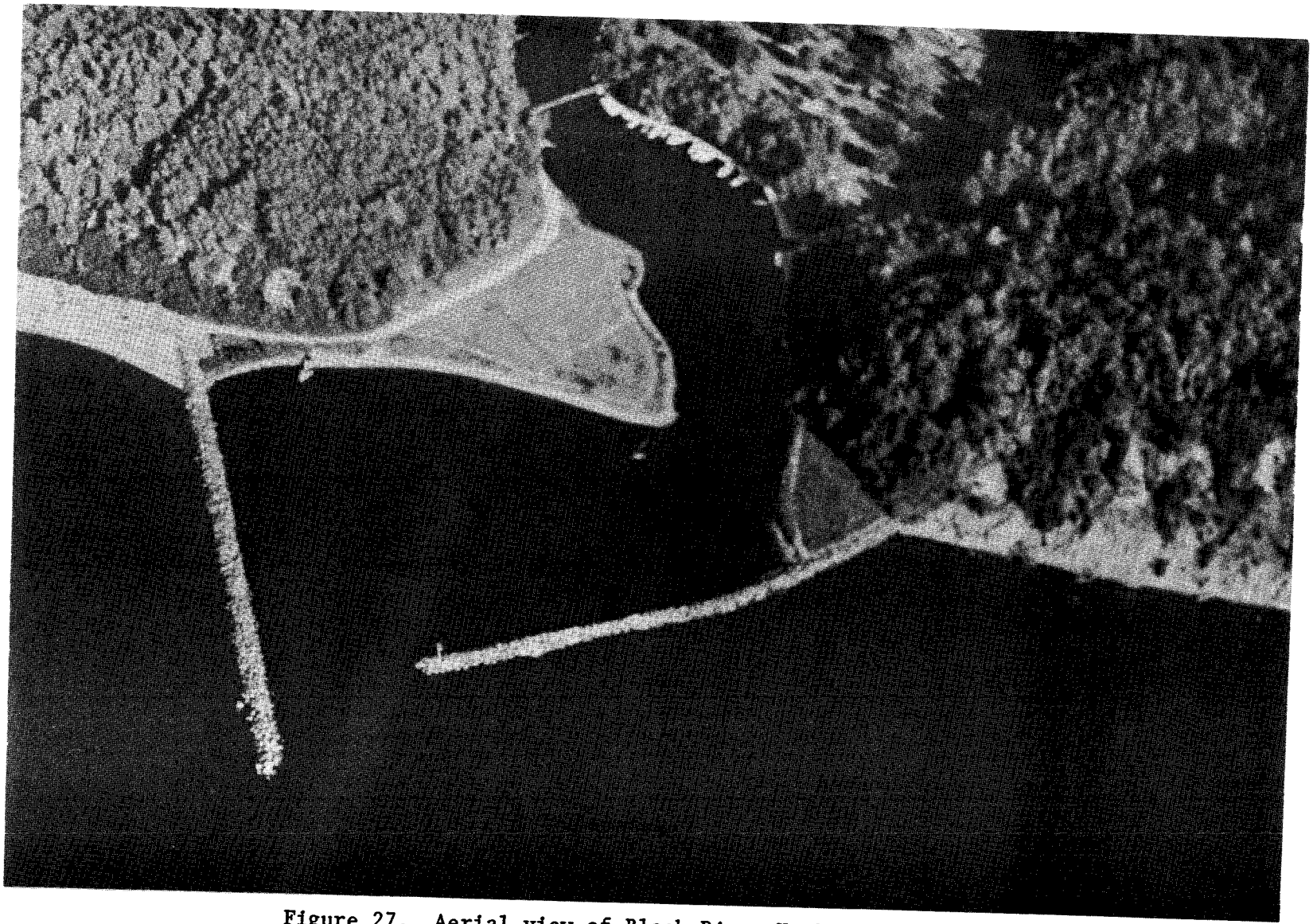


Figure 27. Aerial view of Black River Harbor, Michigan

Table 12

Ontonagon Harbor Piers

Ontonagon, Michigan

Date(s)	Construction and Rehabilitation History
1868-1872	Construction of the inner 1,069 ft of the west pier (Figures 28 and 29, Section E) occurred during this time. This structure consisted of woodpiling filled with stone. The pier width ranged from 8.5 to 11 ft.
1868-1879	The outer 1,515 ft of the east pier (Figures 28 and 29, Section A) was built during this period. This was a rock-filled timber crib structure. The pier was 20 ft wide and had stone toe protection at its base.
1875-1890	Construction of 1,398 ft of the west pier (Figures 28 and 29, Section A) progressed. The pier had the same cross section as the pier built during 1868-79.
1881-1882	Construction of an additional 255 ft of the east pier (Figures 28 and 29, Section B) was completed. This was a 20-ft-wide stone-filled timber crib structure with stone toe protection.
1882-1888	The inner 545 ft of the east pier (Figures 28 and 29, Section C) was built. This pier also was a stone-filled timber crib structure with a 20-ft crest width.
1920-1935	A stone superstructure was built on 1,515 and 1,398 ft of the east and west piers, respectively (Figure 29, Section A). The el of these piers was +5 ft lwd.
1933	A concrete cap (superstructure) was constructed on the inner 1,069 ft of the west pier (Figure 29, Section E). The el of the channel side of the pier was +4 ft lwd.
1935-1936	A stone and concrete cap (superstructure) was installed on 800 ft of the east pier (Figure 29, Sections B and C). The shoreward 545 ft of structure had a crest el of +5 ft lwd (Section C), while the remaining pier had an el of +6 ft lwd (Section B).
1947	The 96-ft-long west pierhead was rebuilt with steel sheetpiling that was stone filled. It was capped with 5-ton minimum cover stone. The pierhead was 22 ft wide with a crest el of +6 ft lwd. Riprap was installed to provide toe protection. It is not clear when the pierhead was originally constructed.
1983	A structural inspection of the piers was made. A void up to 20 ft wide was observed on the west pier, and sand was being lost through the cribbing under the superstructure. Additional stone was required

(Continued)

Table 12 (Concluded)

Date(s)	Construction and Rehabilitation History
	at various locations on both piers, and it was noted that the concrete superstructure had spalled in areas. In the summer of this year, core and cover stone were placed where necessary to repair the structures.
1986	The piers presently are in fair condition. An aerial view of Ontonagon Harbor piers is shown in Figure 30.

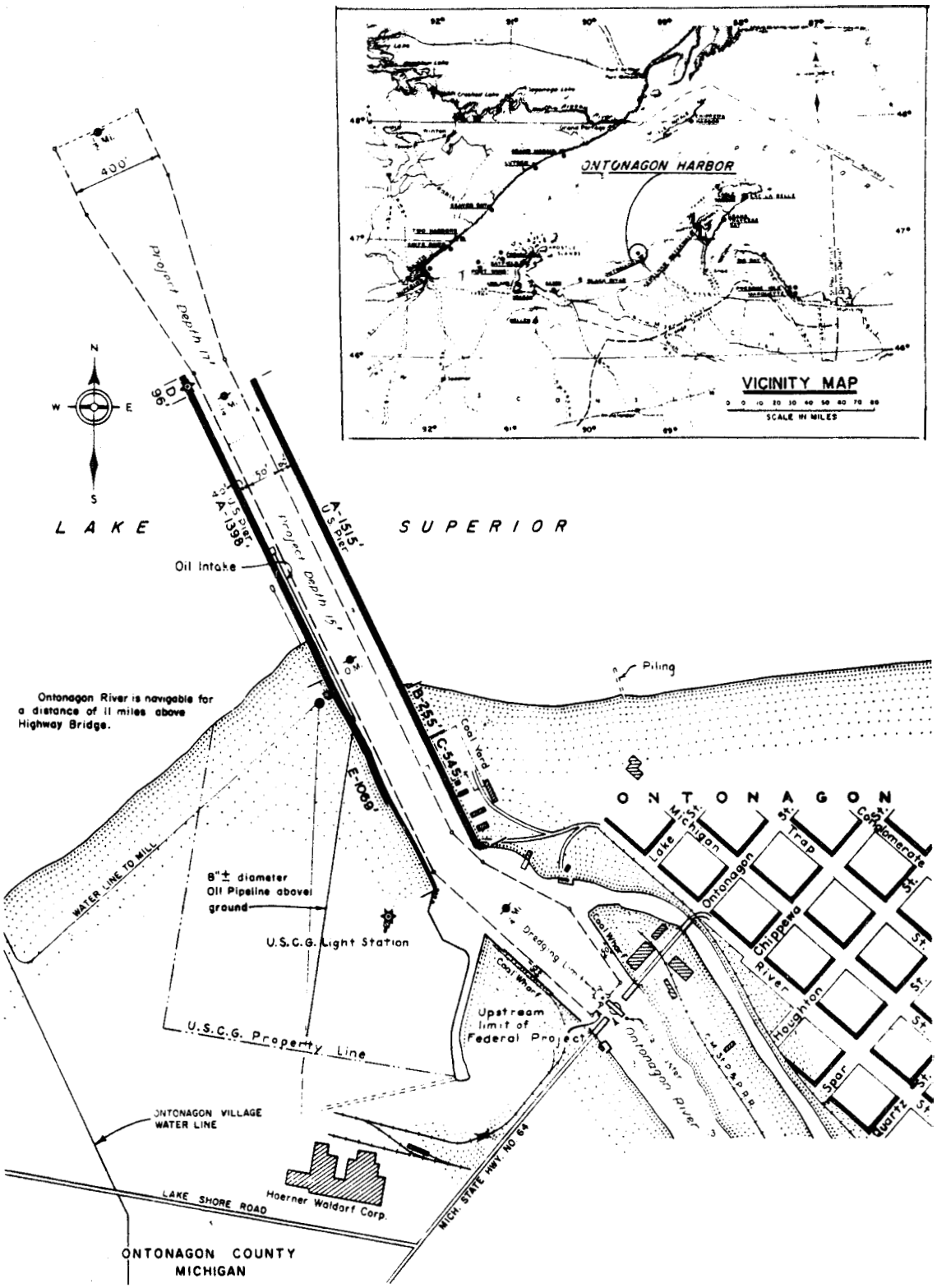


Figure 28. Ontonagon Harbor, Michigan

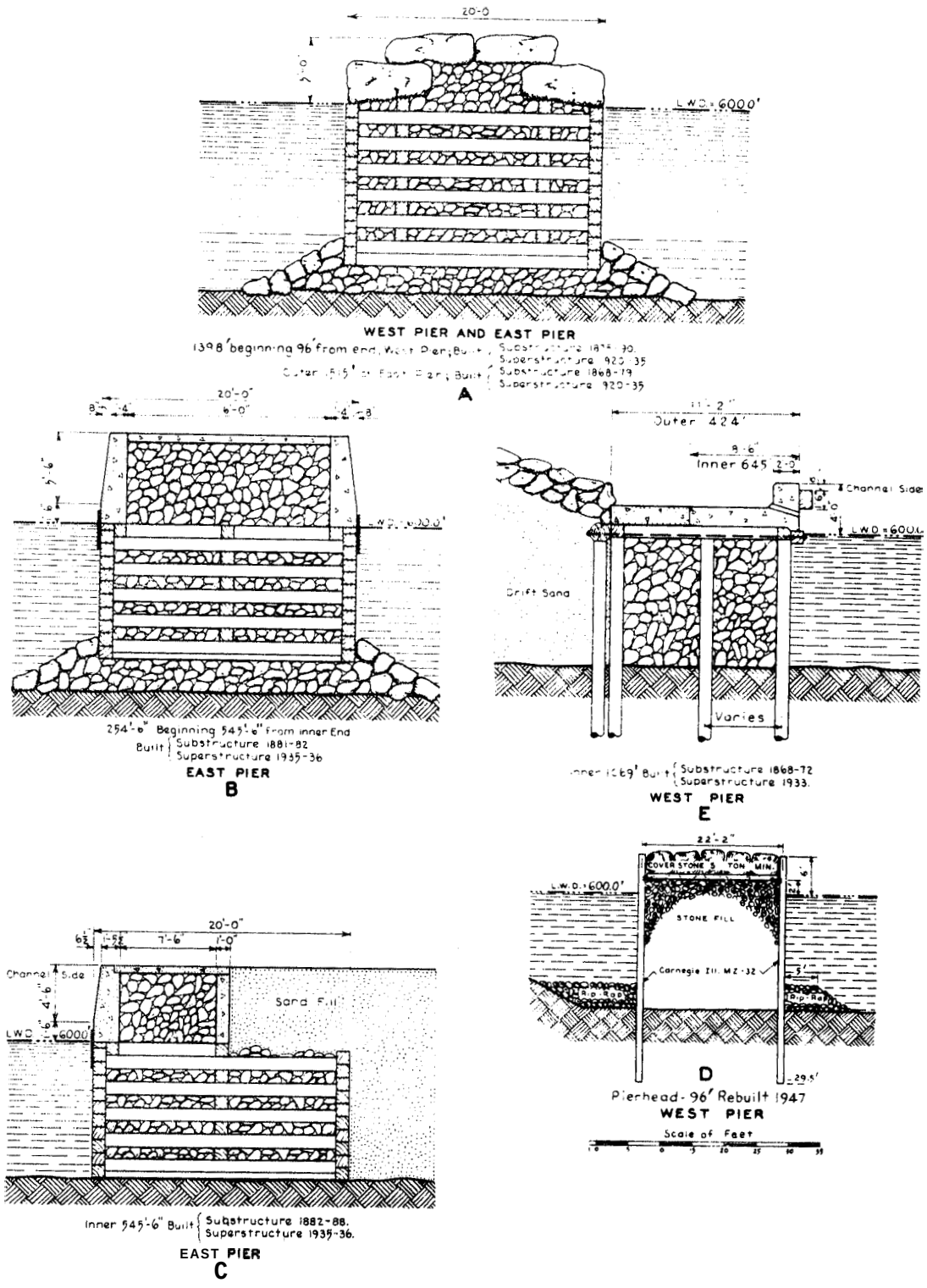


Figure 29. Typical pier cross sections, Ontonagon Harbor, Michigan

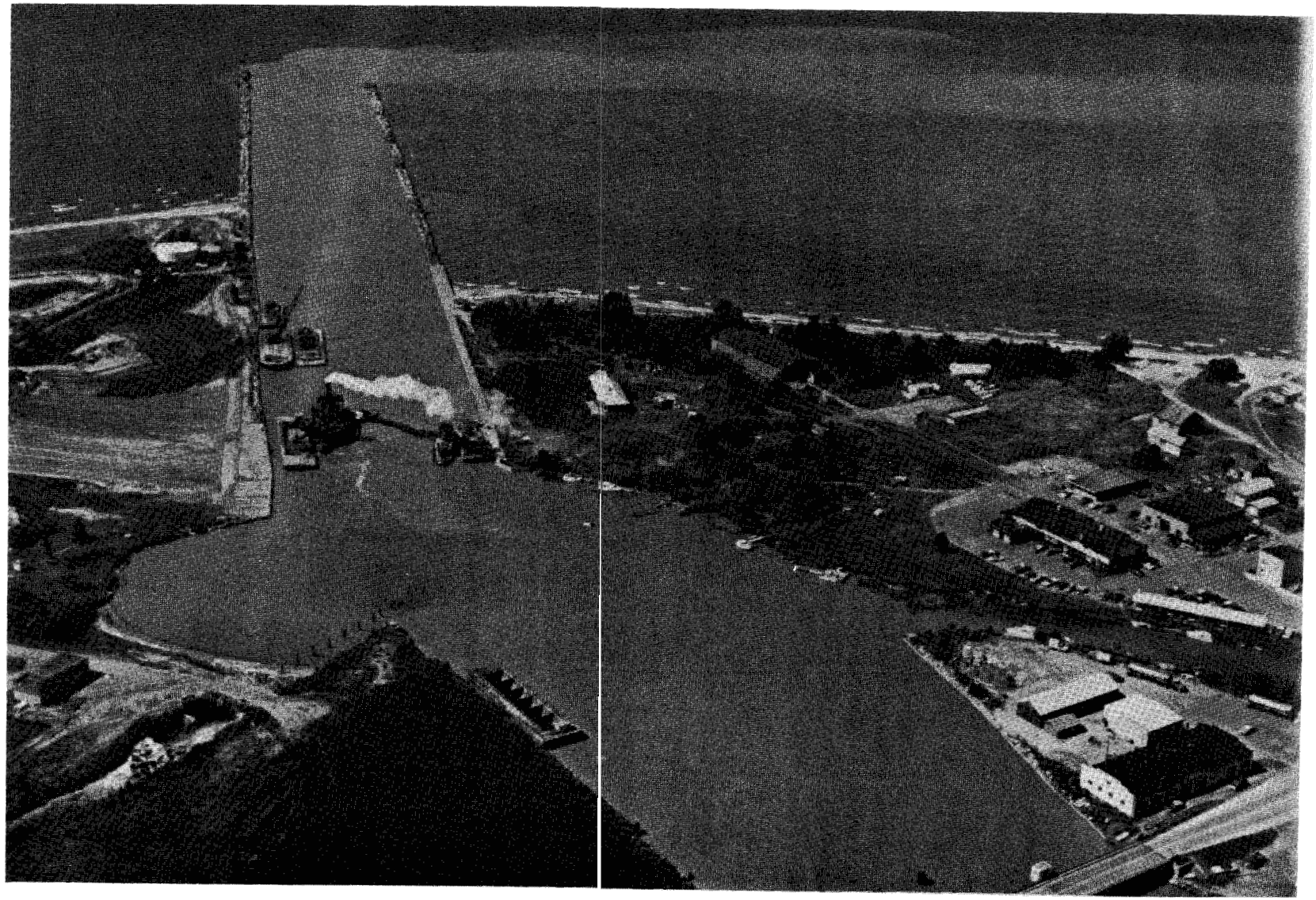


Figure 30 Aerial view of Ontonagon Harbor Michigan

Table 13

Keweenaw Waterway Structures

Keweenaw Waterway, Michigan

Date(s)	Construction and Rehabilitation History
	North (Upper) Entry
1898-1902	A 2,385-ft-long east breakwater and a 2,645-ft-long west breakwater were constructed at the north entrance during this time (Figure 31, Sections C and D). These structures were stone-filled timber crib breakwaters. The shore wings were 20 ft wide, and the main breakwaters were 30 ft wide.
1917-1931	The main breakwaters (Figures 31 and 32, Section C) were capped with 5-ton stone. Fifteen-ton stone was placed on the channel side of the structure for stability of the cap. The el of the structure was +8 ft lwd. Rubble was placed on the lakeward side of the structure on a 1-V:1.5-H slope and capped with 10-ton stone.
1933	The inner wings of the breakwaters (Figures 31 and 32, Section D) were capped with a stone fill and concrete. The el of the structures ranged from +5 to +7 ft lwd. Rubble toe protection also was installed.
1948-1949	Construction of the breakwater pierheads (Figures 31 and 32, Sections A and B) progressed during this period. The 50-ft-long east pierhead was built with steel sheet piles and sand, and the outer cover of the entire structure was built with concrete. The crest el of the structure was +18 ft lwd. The west pierhead was 50 ft long and constructed of concrete and steel sheet piles with a sand fill. The el of the structure was +10 ft lwd.
1986	The breakwaters at the Upper Entry have undergone routine maintenance and presently are in fair condition. Figure 33 is an aerial view of the upper entrance to Keweenaw Waterway.
	South (Lower) Entry
1860	Construction on the inner 950 ft of the breakwater was completed by private interests (Figure 34, Section I-L). This structure was a stone-filled timber crib breakwater. The width of the shoreward 325 ft of breakwater was 13 ft, and the remaining structure was 30 ft wide to a point 912 ft from its origin. At this point, the structure width changed to 24 ft.
1897-1900	The outer 2,764 ft of the breakwater was built by the United States during this period (Figure 34, Sections L-N). The breakwater was a stone-filled timber crib structure with a 24-ft width, except for the lakeward 100 ft which was 30 ft wide.

(Continued)

Table 13 (Concluded)

Date(s)	Construction and Rehabilitation History
	South (Lower) Entry
1920	The outer 50 ft of the breakwater was capped with concrete (Figures 34 and 35, Section N). The crest el of the cap was +5.5 ft lwd, and it was 32 ft in width.
1927	The shoreward 912 ft of the structure was capped with stone and concrete (Figures 34 and 35, Sections I-K). The crest of the shoreward 325 ft of breakwater was built at an el of +4.0 ft lwd with the remaining 587 ft installed at an el of +4.5 ft lwd.
1928-1930	During this period a 2,702-ft-long section of the breakwater was capped with stone and concrete (Figures 34 and 35, Section L). A crest el of +6 ft lwd was constructed.
1930	The superstructure of the 50-ft-long pierhead was completed (Figures 34 and 35, Section M). Concrete and stone were used for construction with a crest height of +6 ft lwd installed.
1983	An inspection of the Lower Entry breakwater indicated the structure was stable and generally in good condition. Extreme spalling of the concrete had taken place in some areas, however, and some areas of the breakwater were in need of additional stone fill.
1986	The breakwater at the Lower Entry presently is in fair to good condition.

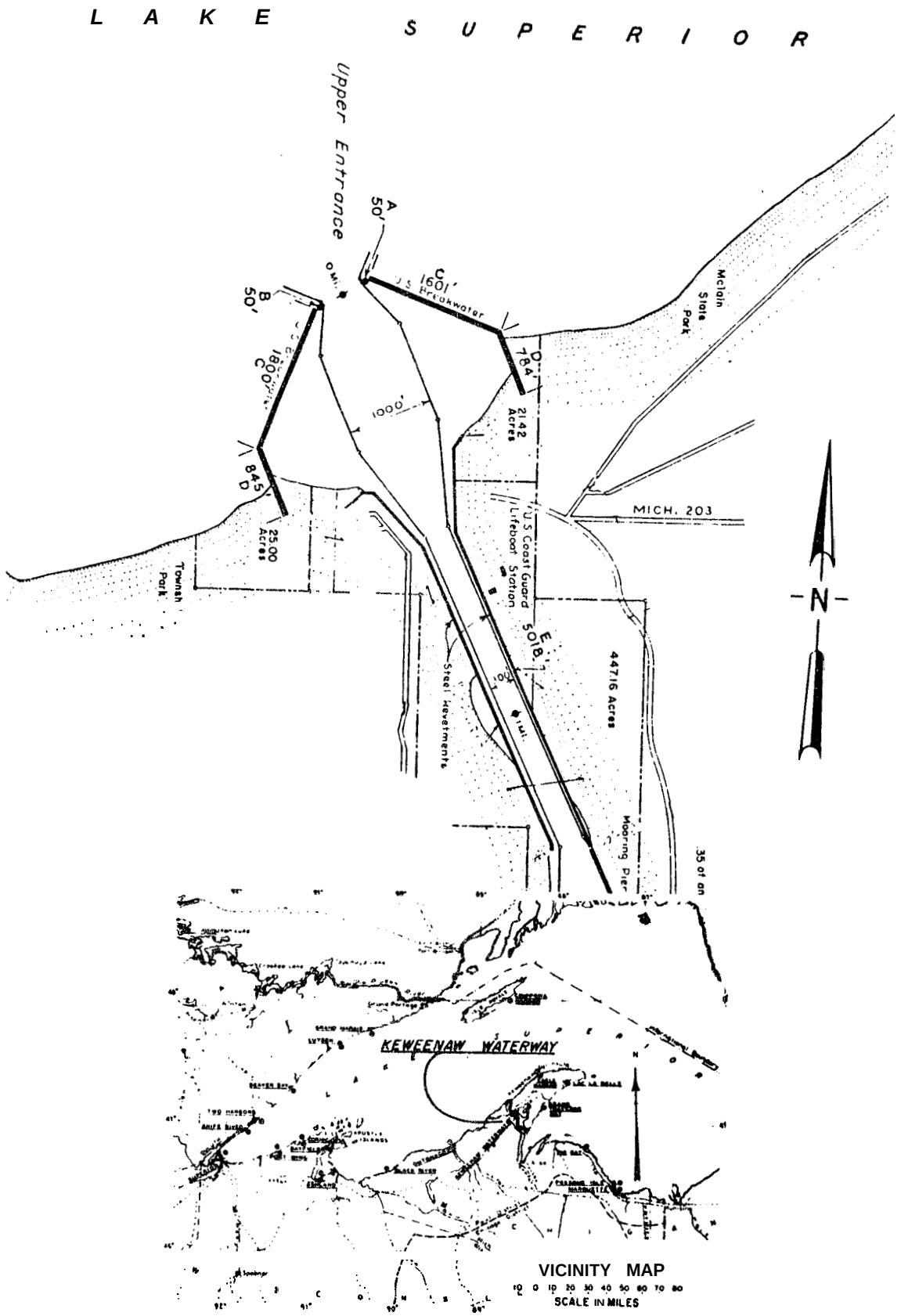
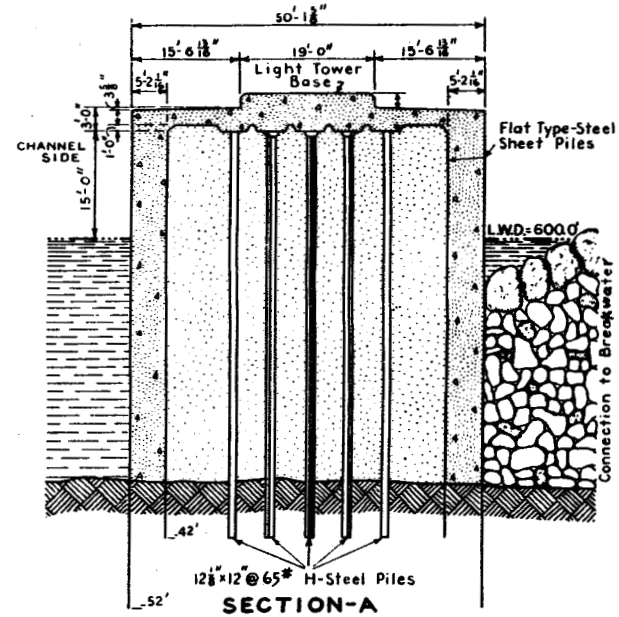
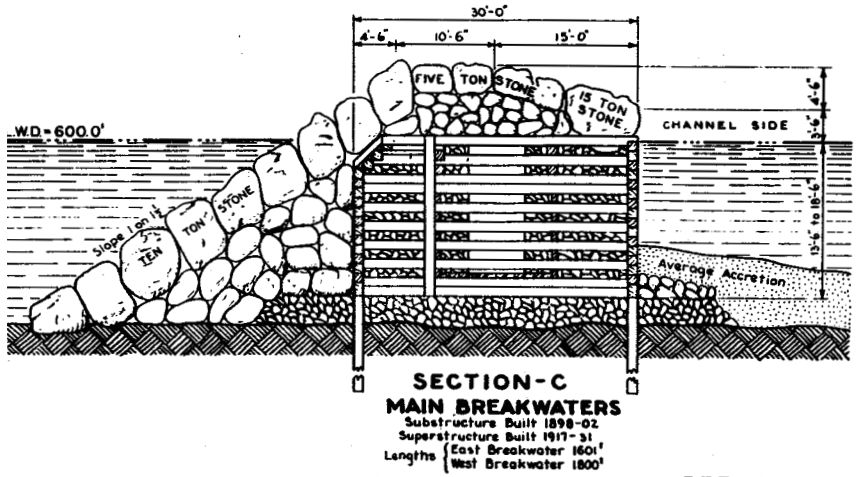


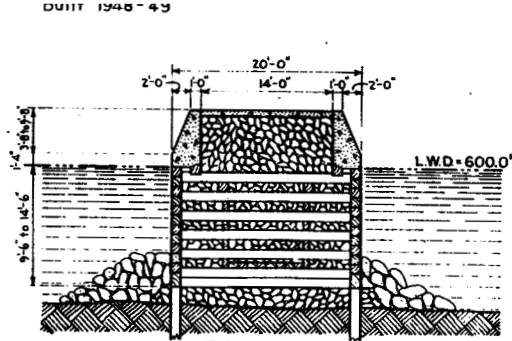
Figure 31. Upper entrance, Keweenaw Waterway, Michigan



SECTION-A
EAST PIERHEAD
Built 1948-49



SECTION-C
MAIN BREAKWATERS
Substructure Built 1898-02
Superstructure Built 1917-31
Lengths { East Breakwater 1601'
West Breakwater 1800'



SECTION-D
SHORE WINGS
Substructure built 1898-1902
Superstructure built 1933
Lengths { East Wing { 764' with concrete cap.
20' now buried in sand.
West Wing { 499' with Concrete cap
346' now buried in sand.

BREAKWATERS AT UPPER ENTRANCE

Figure 32. Upper entrance typical structure cross sections, Keweenaw Waterway, Michigan

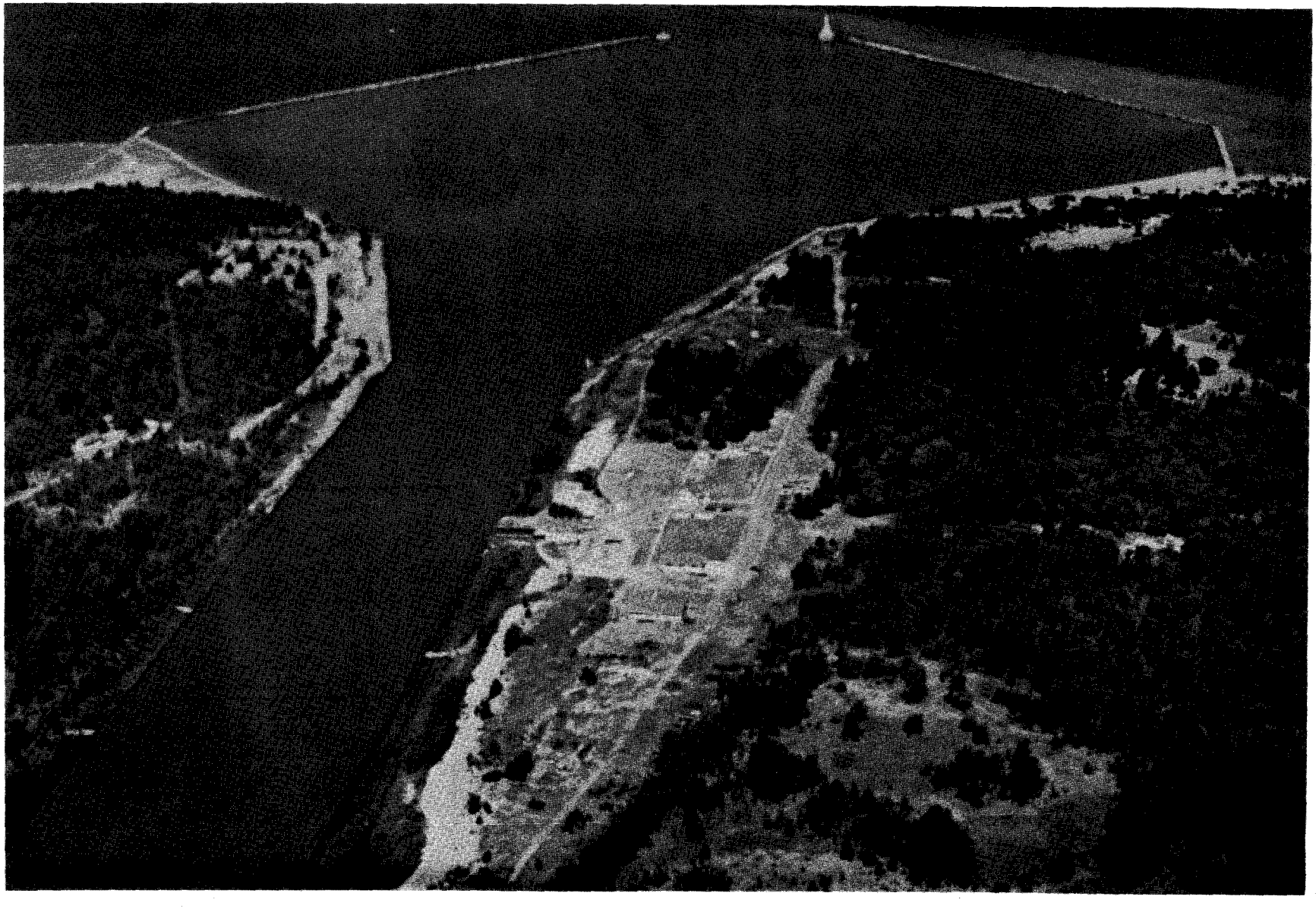


Figure 33. Aerial view of upper entrance to Keweenaw Waterway, Michigan

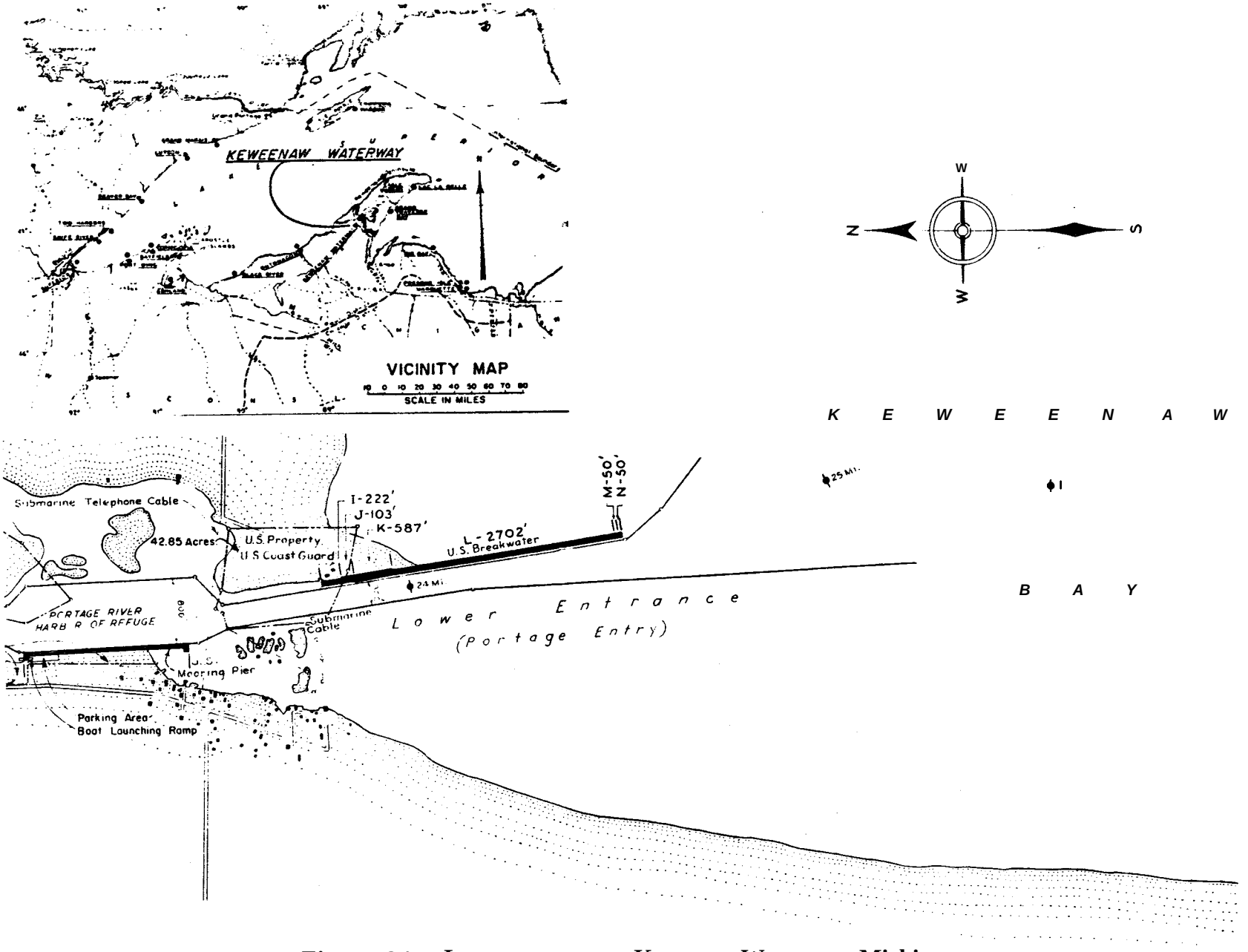


Figure 34. Lower entrance, Keweenaw Waterway, Michigan

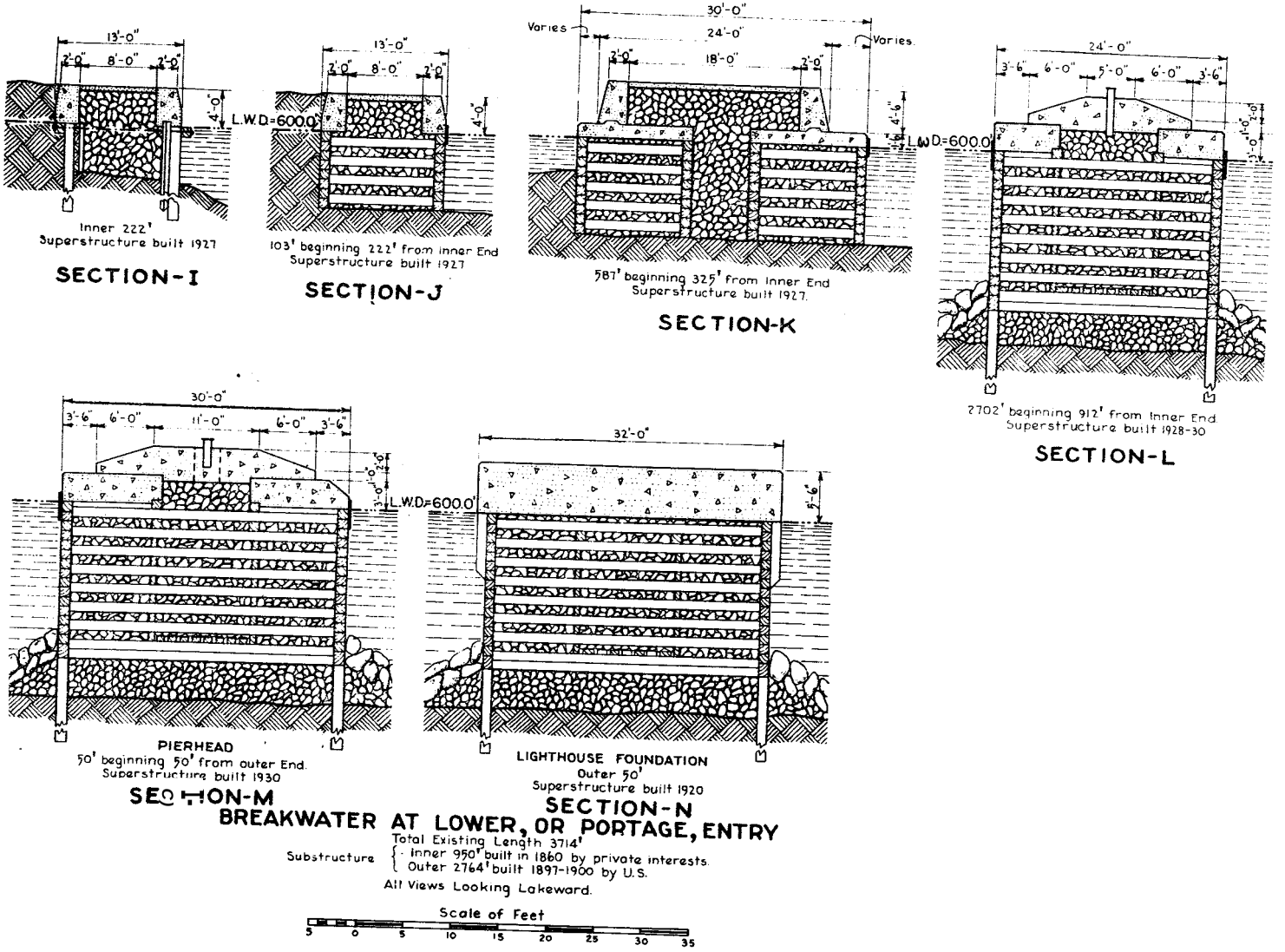


Figure 35. Lower entrance typical breakwater cross secti ∃, Keweenaw Waterway, Michigan

Table 14

Lac La Belle Harbor Breakwaters

Keweenaw County, Michigan

Date(s)	Construction and Rehabilitation History
1959	Construction of two breakwaters was completed at the site (Figure 36). Three consisted of a 490-ft-long north breakwater and a 689-ft-long south breakwater. The north breakwater consisted of a 458-ft steel Z-piling section and a 32-ft cellular steel sheet-pile head. The south breakwater had a 470.5-ft steel Z-piling section with cellular steel sheet piles on the lakeward end cumulating over 218 ft in length (Figure 36). The Z-piling and the cellular structures were both built to an el of +8 ft lwd. The cellular sheet piles were 32 ft in diameter and were sand filled with a 2-ft rock cap (Figure 37). Rock toe protection was provided on the lakeside of the outer cells on the south breakwater.
1983	An inspection of the structures revealed a tipped section toward the channel on the south breakwater about 50 ft shoreward of the cells. Subsequently, the tipped section was straightened, and stone was added on the channel side to prevent scour.
1986	The breakwaters presently are in good condition. An aerial view of Lac La Belle Harbor breakwaters is shown in Figure 38.

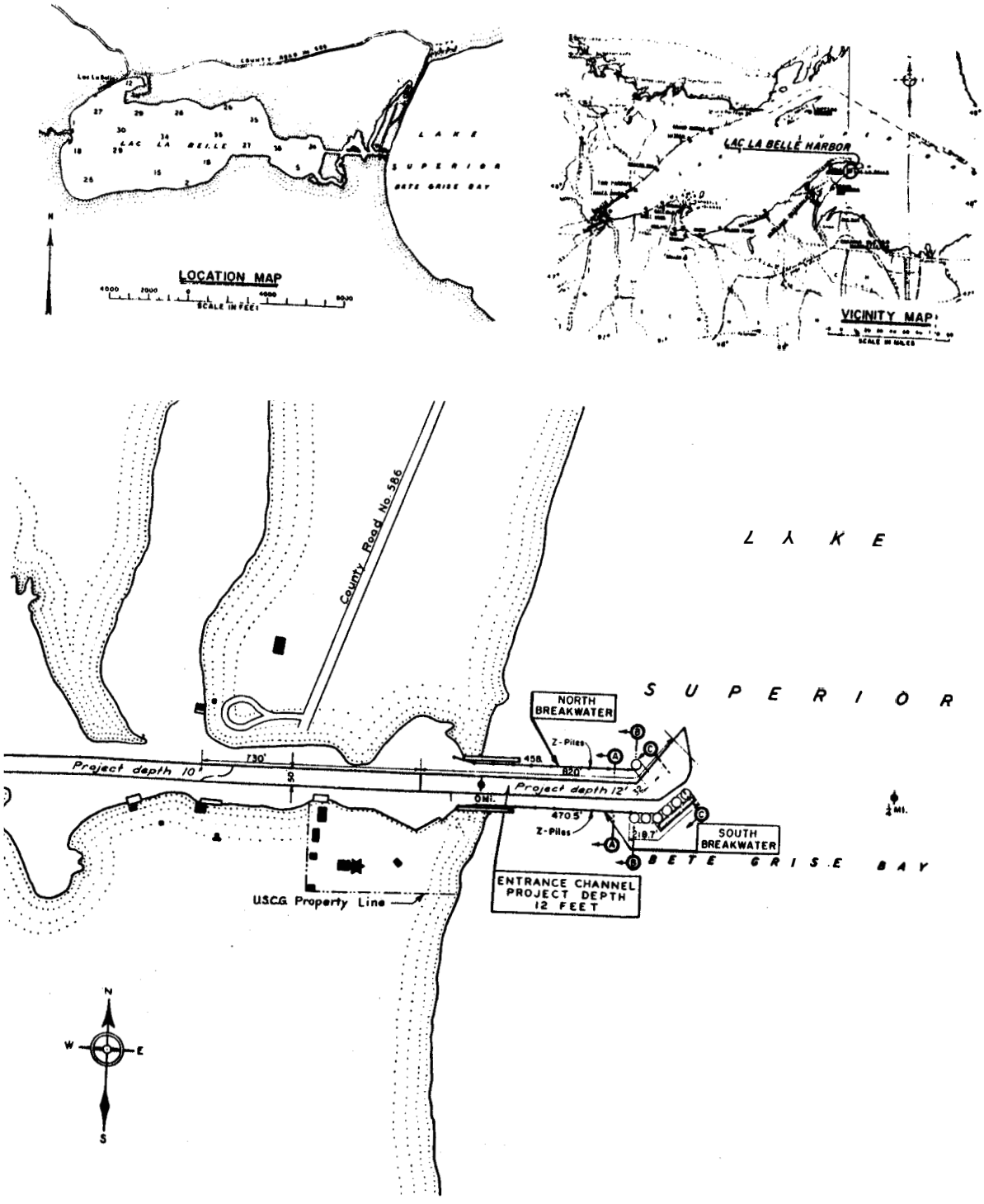
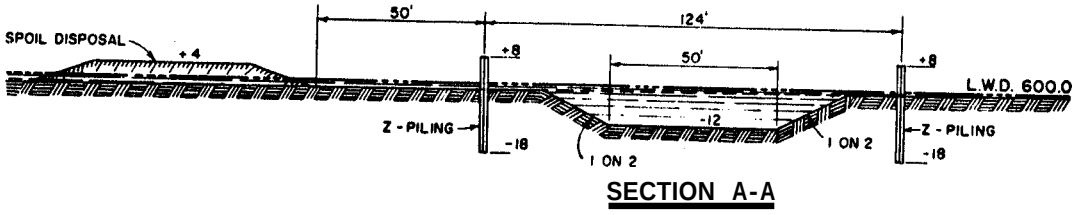
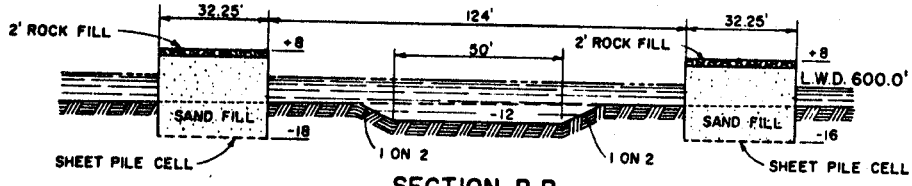


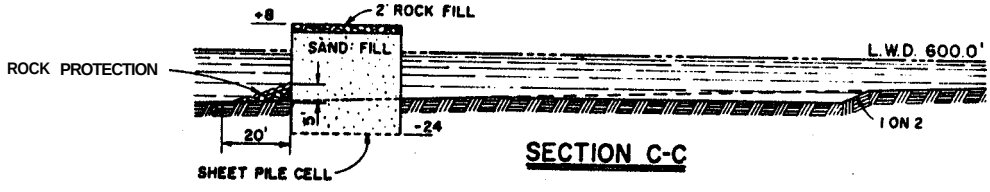
Figure 36. Lac La Belle Harbor, Michigan



SECTION A-A



SECTION B-B



SECTION C-C

NORTH Z-PILING BREAKWATER = 458.5'
SOUTH Z-PILING BREAKWATER = 470.5'
SOUTH CELL BREAKWATER = 218.7'

BUILT 1959

Figure 37. Typical structure cross sections, Lac La Belle Harbor, Michigan

Figure 38. Aerial view of Lac La Belle Harbor, Michigan

Table 15

Grand Traverse Bay Harbor Structures

Grand Traverse Bay, Michigan

Date(s)	Construction and Rehabilitation History
1949-1951	Construction of two piers at the site (Figure 39) progressed during this time. The north pier was 707 ft long, and the south pier was 567 ft long. The shoreward portions of the piers (Figures 39 and 40, Sections D and E) were built with steel sheet pile at an el of +6.5 ft lwd. They were backfilled with sand except at the top where a rock surface was installed. The 111-ft-long section of the north pier at the water's edge (Figures 39 and 40, Section C) was a sand-filled sheet-pile structure. It was 12 ft wide with an el of +8 ft lwd. The structure was capped with 2-ton (minimum) stone and 3-ton (minimum) stone placed on the lakeside to an el of approximately +4.5 ft lwd. A 307-ft-long section of the north pier, and the lakeward portion of the south pier (Figures 39 and 40, Section B) were built with steel sheetpiling. The structure was sand filled with a concrete cap installed at an el of +6 ft lwd. The pier was 11.5 ft wide, and stone toe protection was included. The outer end of the north pier (Figures 39 and 40, Section A) was of similar construction except it was capped with 2-ton (minimum) stone at an el of +8 ft lwd and was 14.5 ft wide.
1964	Construction of a 164-ft-long north pier extension was completed (Figures 39 and 40, Section F). Cellular steel sheet piles with diameters of 37.3 ft were used. These cells were sand filled with 2-ft-thick rock (filled with grout) caps. The el of the cellular structures was +8 ft lwd, and stone toe protection was installed on the lakeward side.
1975	A 180-ft-long cellular sheet-pile north breakwater extension was completed (Figure 39).
1979	An inspection of the piers indicated that repairs were needed on the cap of the north pier at the intersection of the cell and Section A. Additional repairs were needed on the outer three cell caps.
1981	The north pier caps, identified in need of repair in 1979, were repaired.
1983	An inspection of the structures revealed that the cap on the south pier had settled as much as 6 in. in some areas. The outer cell of the north pier also had settled (up to 14 in.) and had several large cracks. Additional riprap stone also was required at Section C. Repairs to the structures were subsequently made.
1986	The piers presently are in good condition. An aerial view of Grand Traverse Bay Harbor structures is shown in Figure 41.

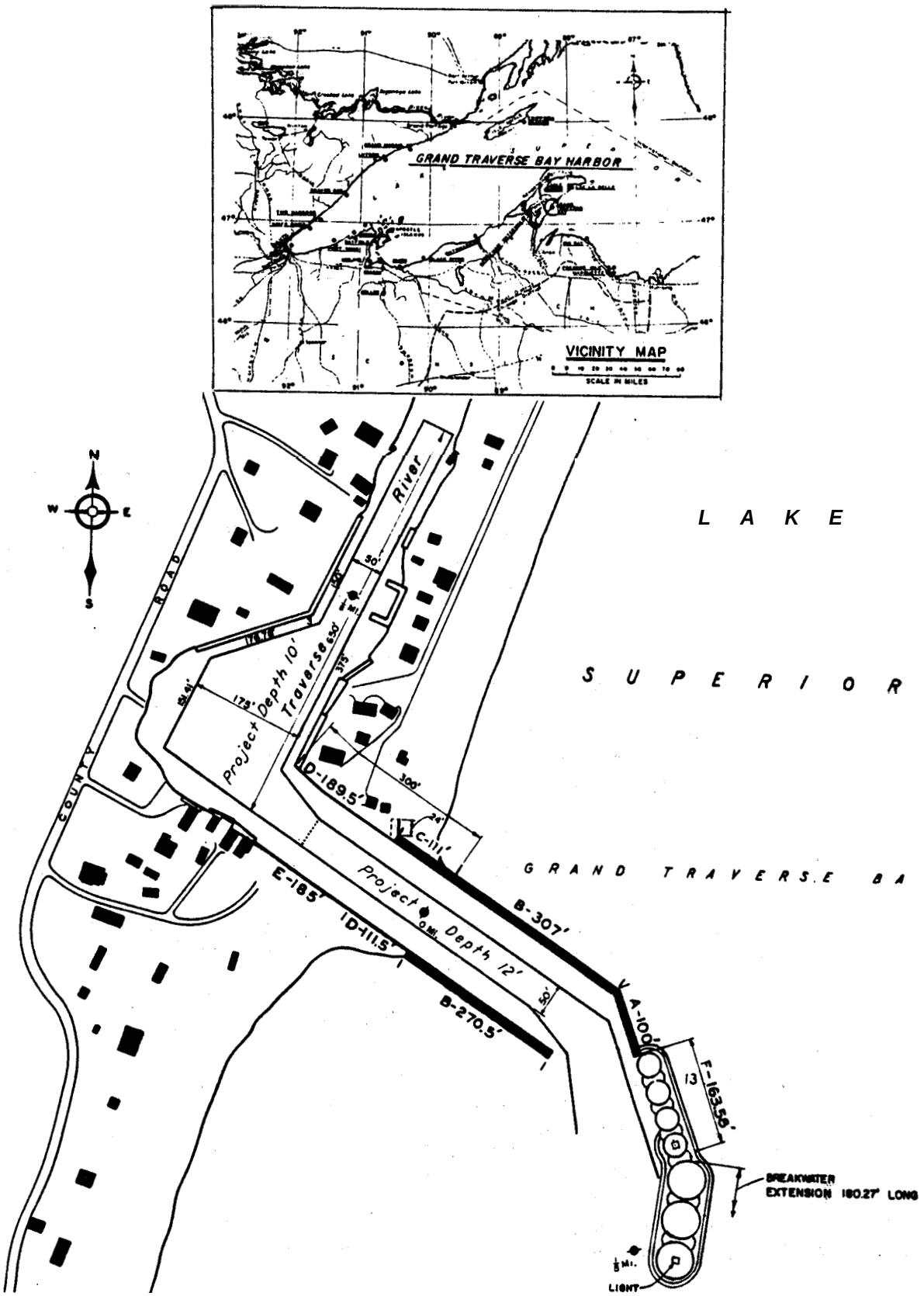


Figure 39. Grand Traverse Bay Harbor, Michigan

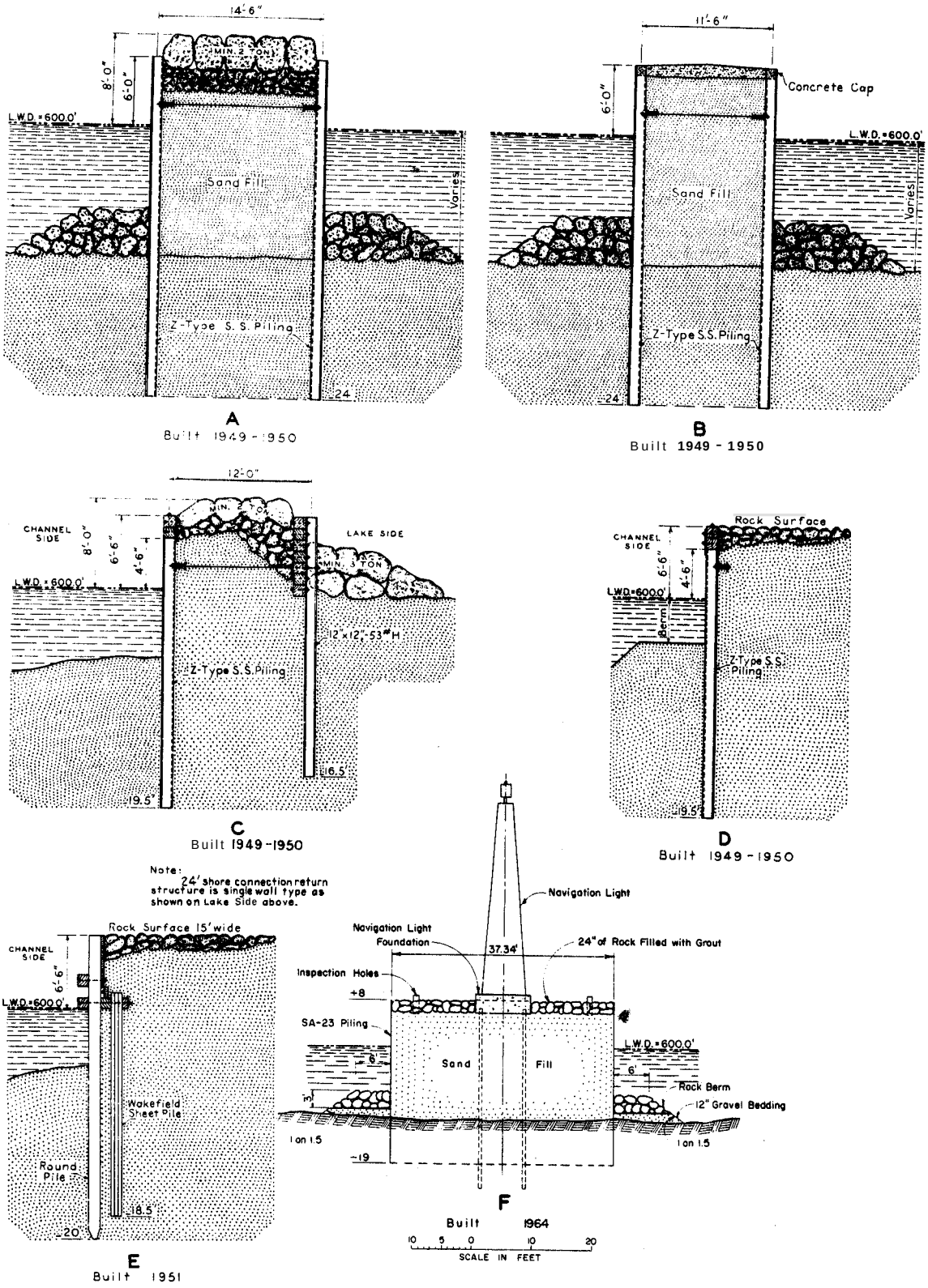


Figure *40*. Typical structure cross section, Grand Traverse Bay Harbor, Michigan

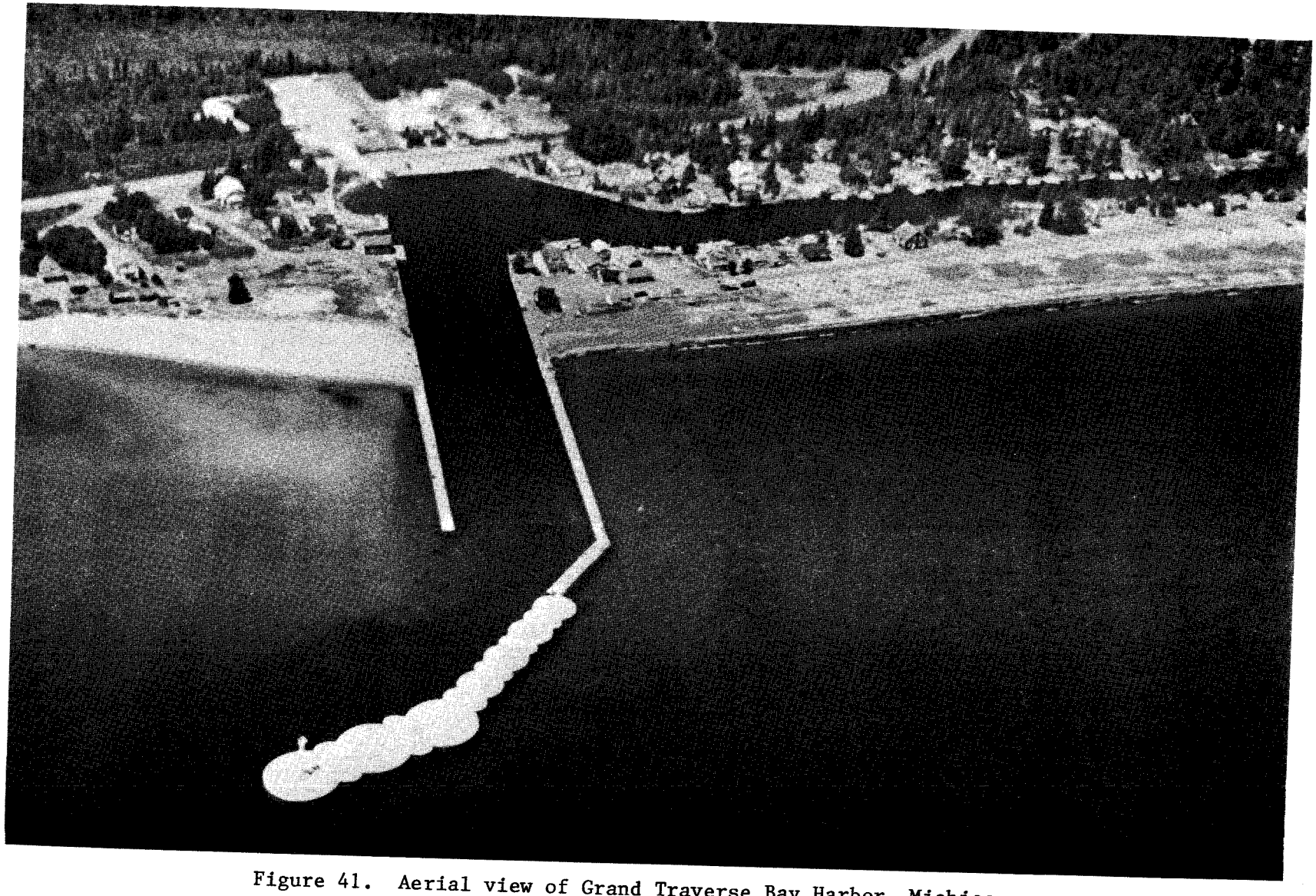


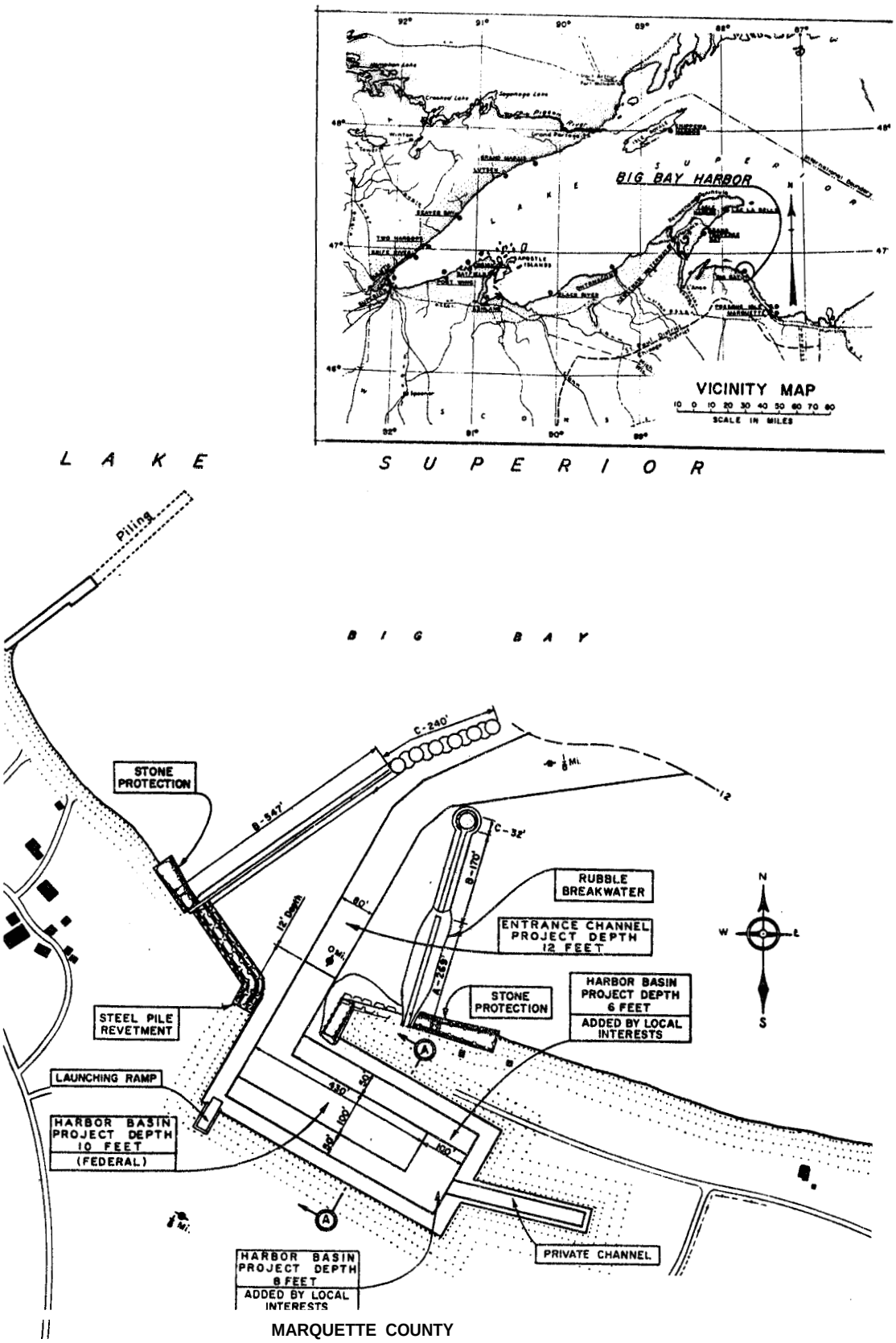
Figure 41. Aerial view of Grand Traverse Bay Harbor, Michigan

Table 16

Big Bay Harbor Breakwaters

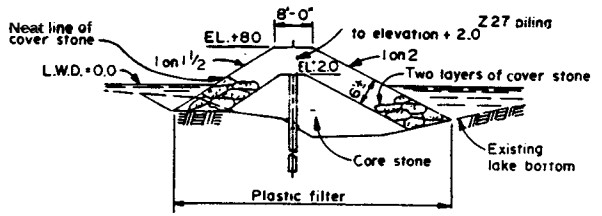
Big Bay, Michigan

Date(s)	Construction and Rehabilitation History
1960	Construction of a 471-ft-long east breakwater and a 787-ft-long west breakwater was completed at the site (Figure 42). The shoreward 269-ft-long portion of the east breakwater was rubble-mound (Figures 42 and 43, Section A). It had an 8-ft crest width and a +8-ft lwd crest el. Slopes on the lakeside were 1V:2H, and on the harbor side they were 1V:1.5H. The structure was built around steel sheet-piling which had an el of +2 ft lwd. From this point lakeward a steel sheet-pile structure extended an additional 170 ft (Figures 42 and 43, Section B). The shoreward 547 ft of the west breakwater utilized the same structure. The sheetpiling had a crest el of +8 ft lwd with stone toe protection on each side. The head of the east breakwater consisted of a cellular sheet pile (32 ft in diameter), and the lakeward 240 ft of the west breakwater was constructed of 36-ft-diameter cellular sheetpile (Figures 42 and 43, Section C). These cells were filled with sand and capped with 2 ft of grout-filled rock. Rubble toe protection was included also.
1969	The east breakwater was rehabilitated.
1979	An inspection of the harbor structures indicated that additional riprap was needed on both sides of the west breakwater (Figure 43, Section B). The stone was eventually placed.
1986	The breakwaters presently are in good condition. An aerial view of Big Bay Harbor breakwaters is shown in Figure 44.



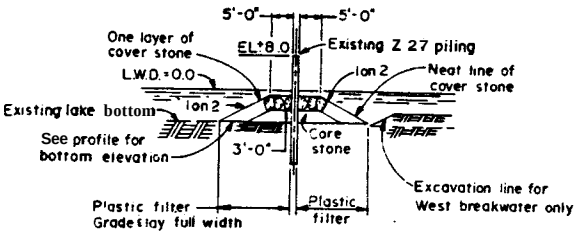
MARQUETTE COUNTY

Figure 42. Big Bay Harbor, Michigan



SECTION A

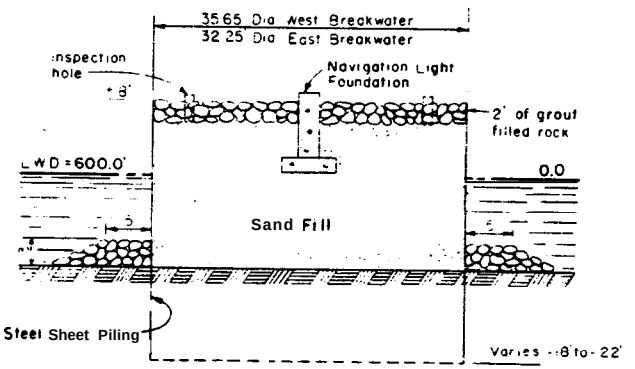
269' East Breakwater



SECTION B

547' West Breakwater
170' East Breakwater

77



C

240 West Breakwater
32 East Breakwater

Built 1960

Figure 43. Typical breakwater cross sections, Big Bay Harbor, Michigan

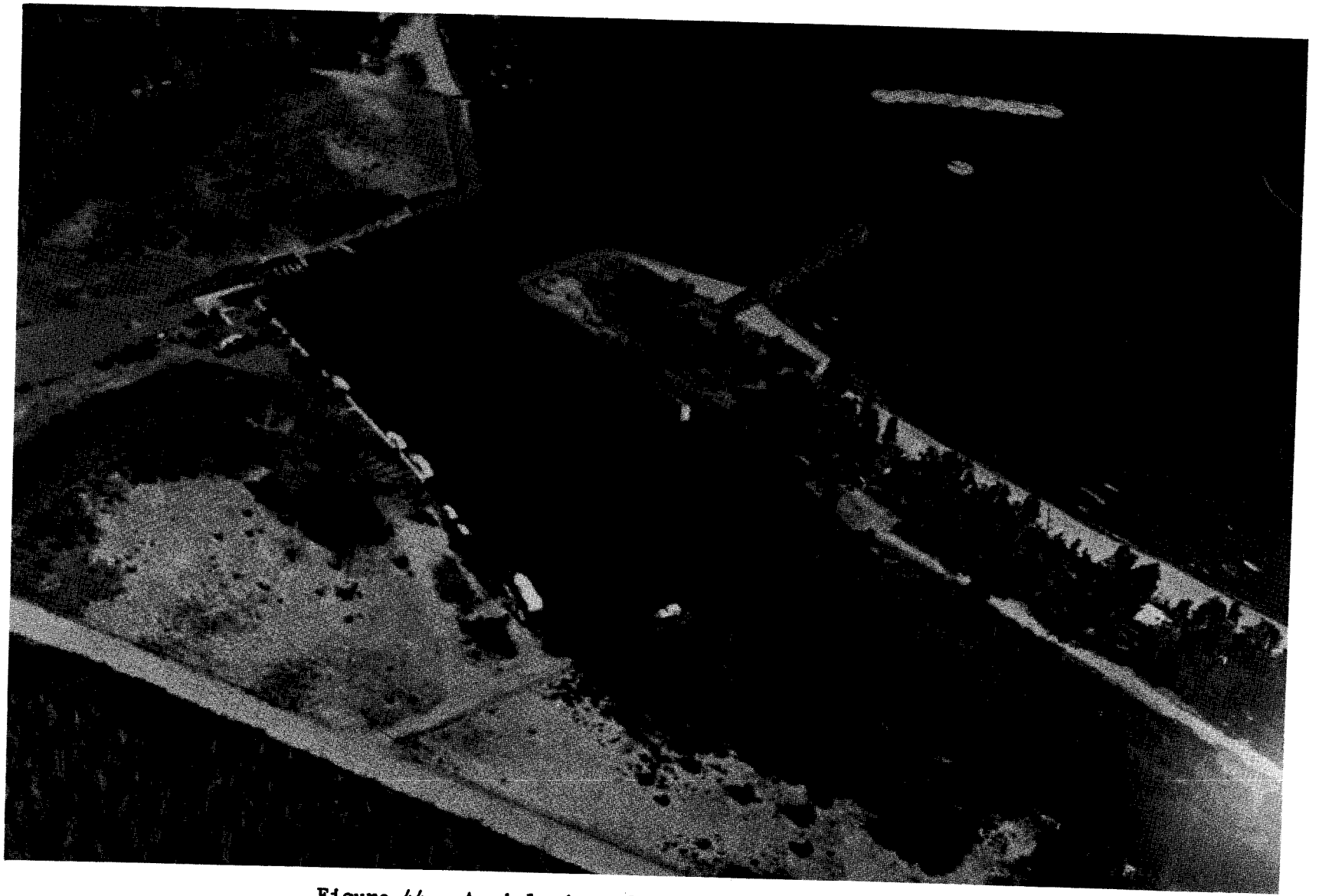


Figure 44. Aerial view of Big Bay Harbor, Michigan

Table 17

Presque Isle Harbor Breakwater

Presque Isle, Michigan

Date(s)	Construction and Rehabilitation History
1897-1901	Construction of a 1,053-ft-long breakwater was performed during this period (Figures 45 and 46, Section B). The structure was a 24-ft-wide stone-filled timber crib breakwater with riprap toe protection.
1903	A 163-ft-long stone-filled timber crib breakwater (16 ft wide) was completed connecting the original structure to shore (Figures 45 and 46, Section A).
1927	A stone and concrete capped superstructure was built on the existing structures (Figures 45 and 46, Sections A and B). The crest el of the structure was +8 ft lwd.
1938	Construction of the breakwater head was completed. The structure was a stone-filled timber crib breakwater that was 30 ft in width (Figures 45 and 46, Section D). The stone portion of the substructure and stone placed on the lakeward side of the breakwater were installed at an el of +8 ft lwd. Armor stone on the lakeside and toe protection on the harbor side of the structure were in the 10-ton range. The concrete superstructure was built to an el of +16 ft lwd for a lighthouse.
1938-1939	A 1,600-ft-long rubble-mound breakwater was constructed connecting the breakwater head to the existing structure (Figures 45 and 46, Section C). The crest was 12 ft wide with an el of +8 ft lwd. Ten-ton armor stone was used.
1963	Riprap cover stone (5.5 ton) was installed for a distance of 180 ft on the harbor side and 400 ft on the lakeward side of the original timber crib structure (Figure 46, Section B). The inner 1,216 ft of breakwater was rehabilitated for a cost of $76,500.
1975	An inspection of the site indicated that the outermost portion of the rubble-mound breakwater needed some minor stone rearranging. This work was completed later in the year.
1986	The breakwater presently is in good condition. An aerial view of Presque Isle Harbor breakwater is shown in Figure 47.

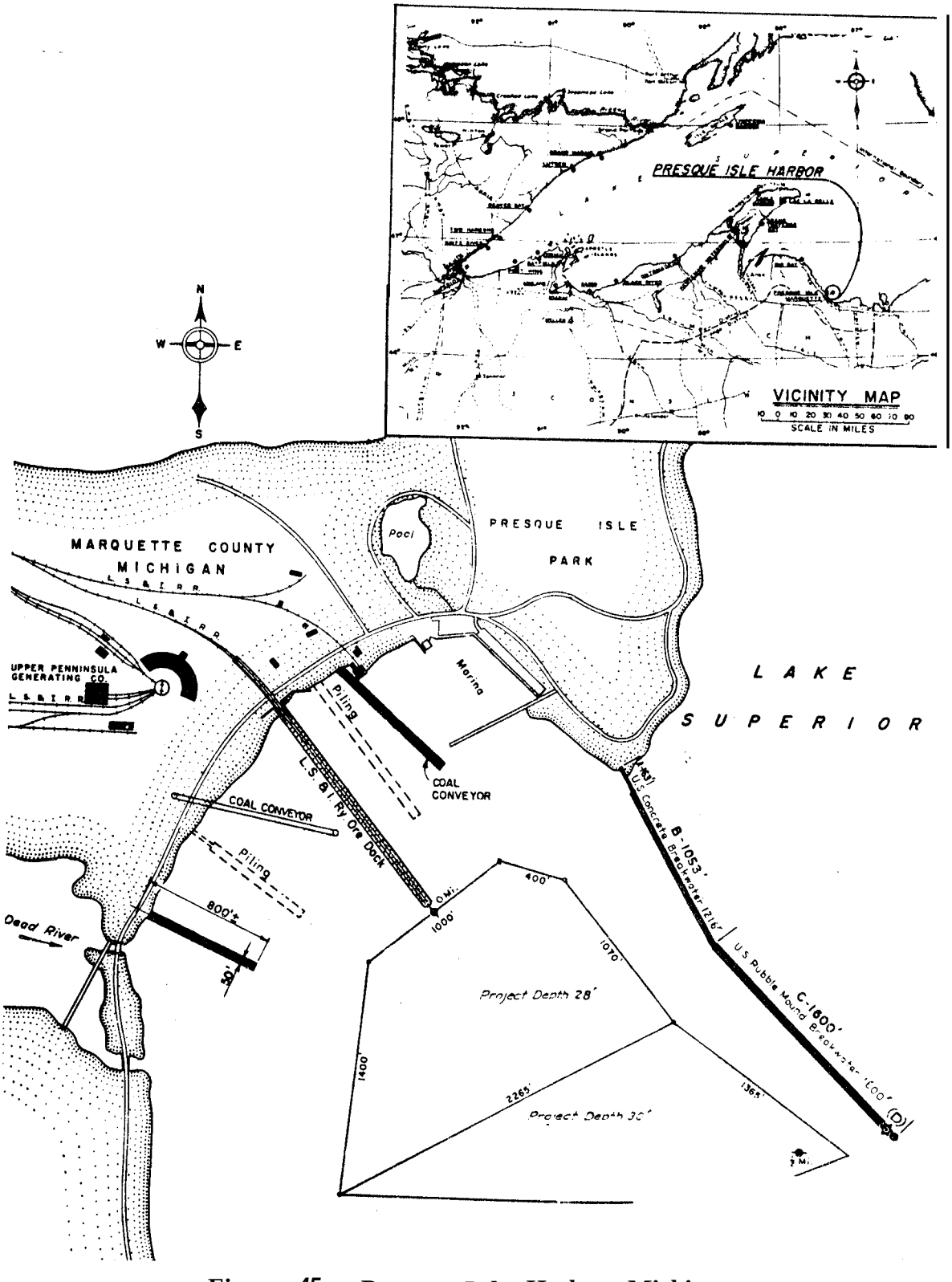


Figure 45. Presque Isle Harbor, Michigan

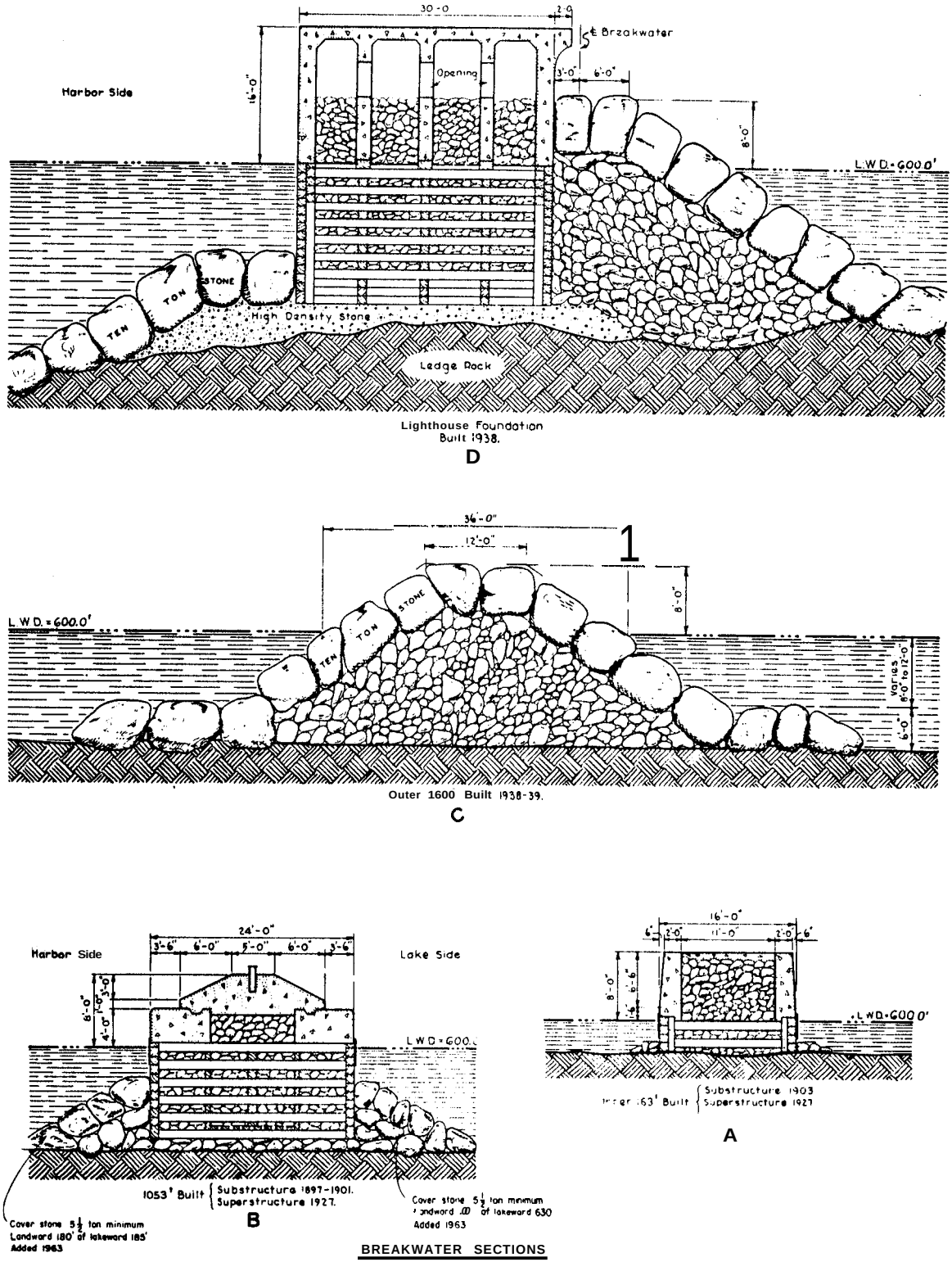


Figure 46. Typical breakwater cross sections, Presque Isle Harbor, Michigan

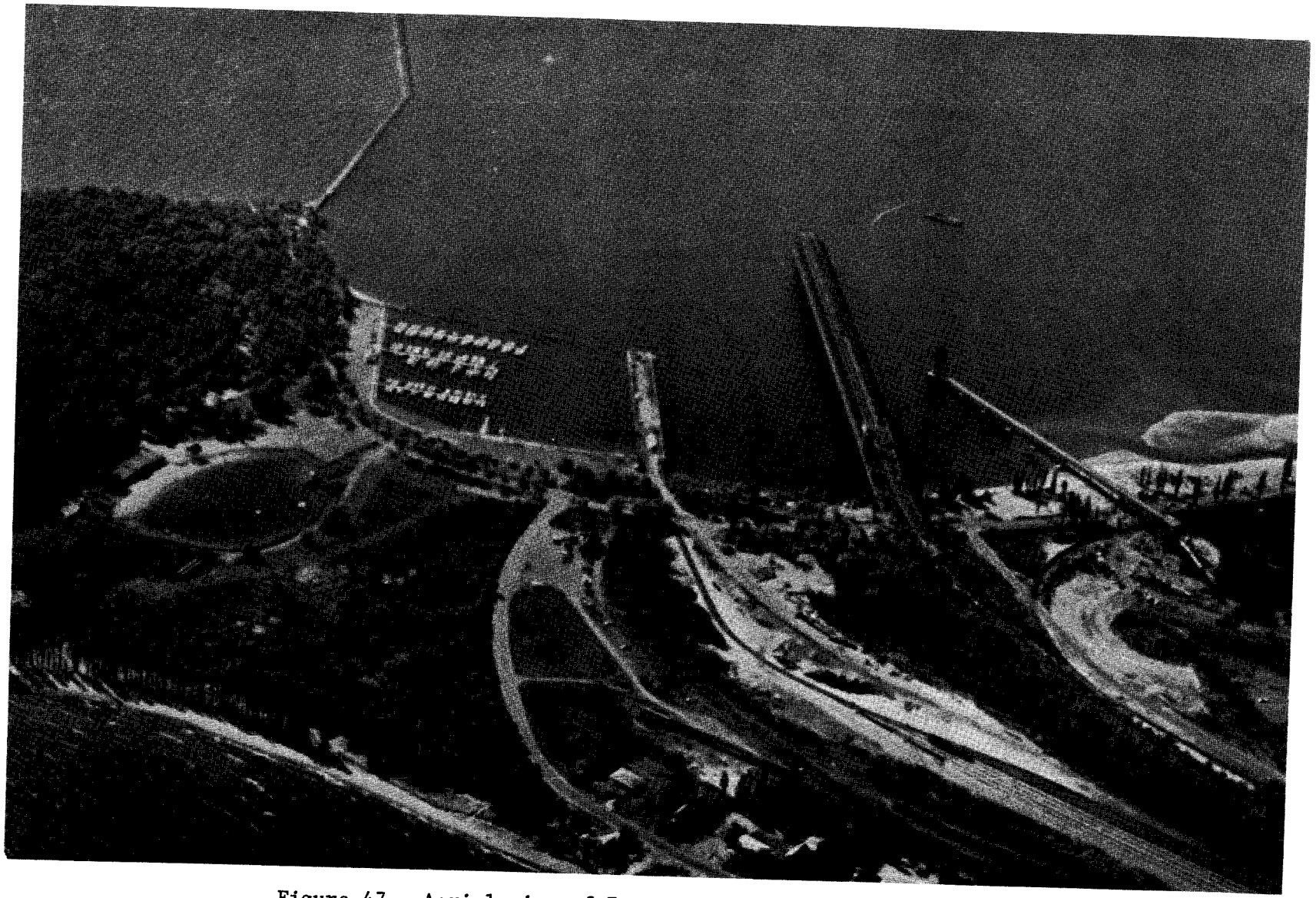


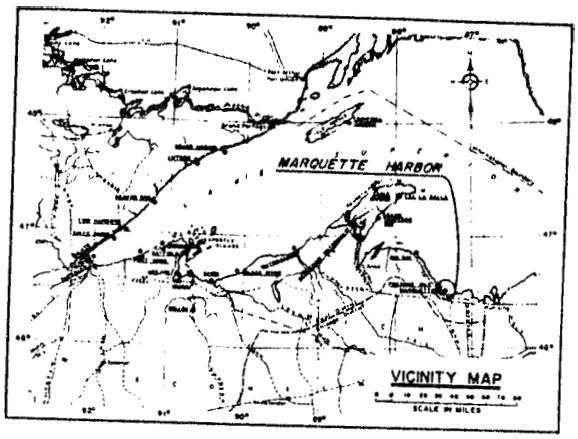
Figure 47. Aerial view of Presque Isle Harbor, Michigan

Table 18

Marquette Harbor Breakwater

Marquette, Michigan

Date(s)	Construction and Rehabilitation History
1867	Construction of the inner 410 ft of the breakwater was completed (Figures 48 and 49, Sections A and B). The structure was a stone-filled timber crib breakwater. The inner 260 ft was 20 ft wide, and the remaining 150 ft was 25 ft wide.
1868-1874	An additional 1,600 ft of breakwater was built during this time. It also was a stone-filled timber crib structure and was 30 ft wide (Figures 48 and 49, Section C).
1889-1894	During this period the breakwater was extended an additional 1,000 ft (Figures 48 and 49, Sections D, E, F, and G). The structure was a stone-filled timber crib breakwater and was 24 ft wide. It was built on a stone base and included riprap toe protection.
1896-1904	A concrete cap (superstructure) was added to the 1,600-ft-long breakwater built during 1868-74 (Figures 48 and 49, Section C). The crest el of the structure was +10 ft lwd.
1897-1905	A concrete cap (superstructure) was installed on the remaining portion of the breakwater (Figures 48 and 49, Sections A, B, D, E, F, and G). The superstructure was built to an el of about +10 ft lwd. Stone was added on the lakeside of the inner 410 ft (Sections A and B), and on both sides of the 123-ft-long section designated as G (Figures 48 and 49).
1912-1918	The breakwater was extended an additional 1,500 ft during this period. The extension consisted of a rubble-mound structure (Figures 48 and 49, Section H). The shoreward 500 ft of structure was installed at an el of +8 ft lwd, and the outer 1,000 ft was constructed to a +10 ft lwd el. The breakwater was constructed of 10-ton armor stone.
1920-1923	Riprap was placed on the lakeside of the 1,600-ft-long breakwater originally constructed from 1868-74 (Figure 49, Section C).
1965	Rehabilitation of the inner 3,010 ft of the breakwater was completed for a cost of $465,747.
1979	Stone placement along a 500-ft section of the breakwater (sta 22+50 to 27+50) was completed. Also the placement of riprap stabilizing stone at the lakeward structure toe was completed.
1986	The breakwater presently is in very good condition. An aerial view of Marquette Harbor breakwater is shown in Figure 50.



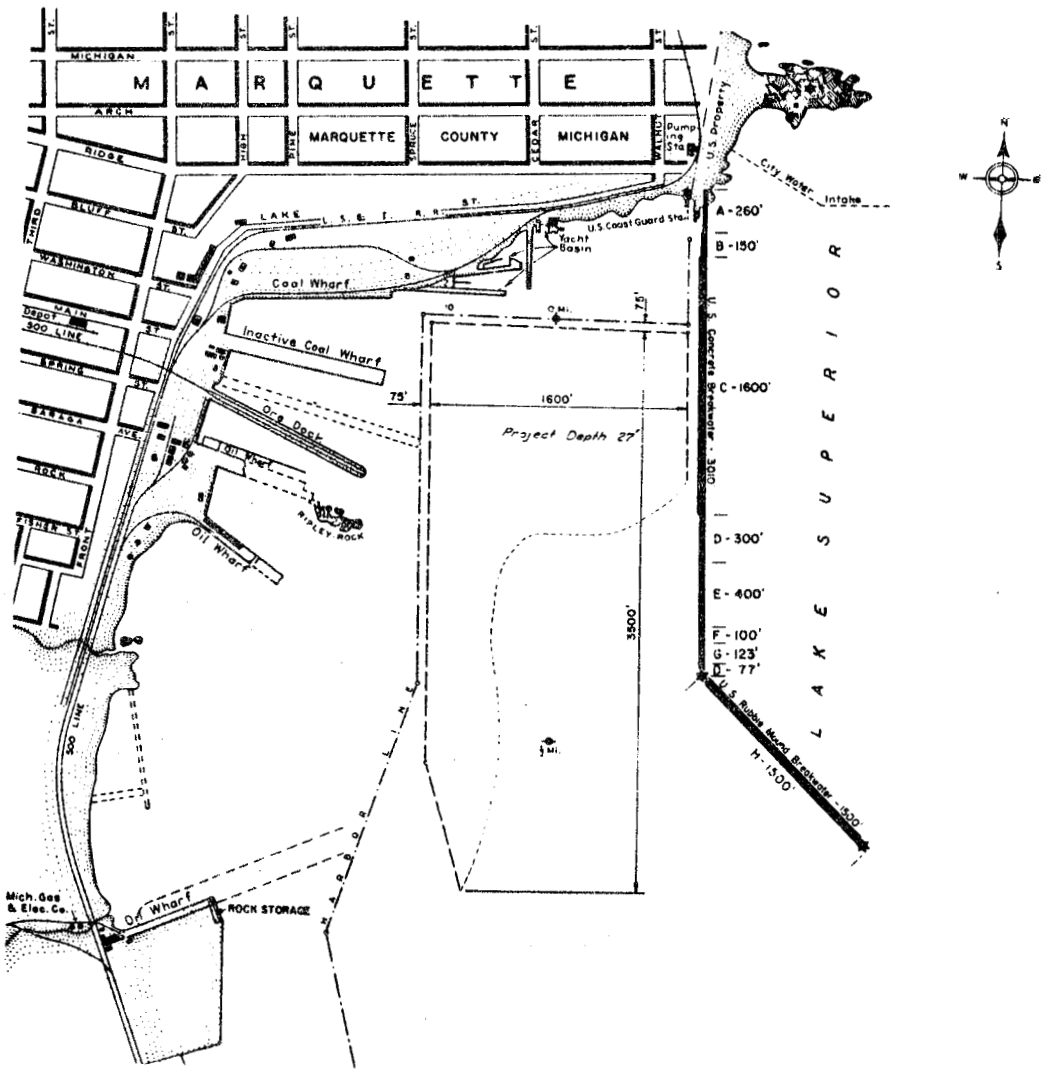


Figure 48. Marquette Harbor, Michigan

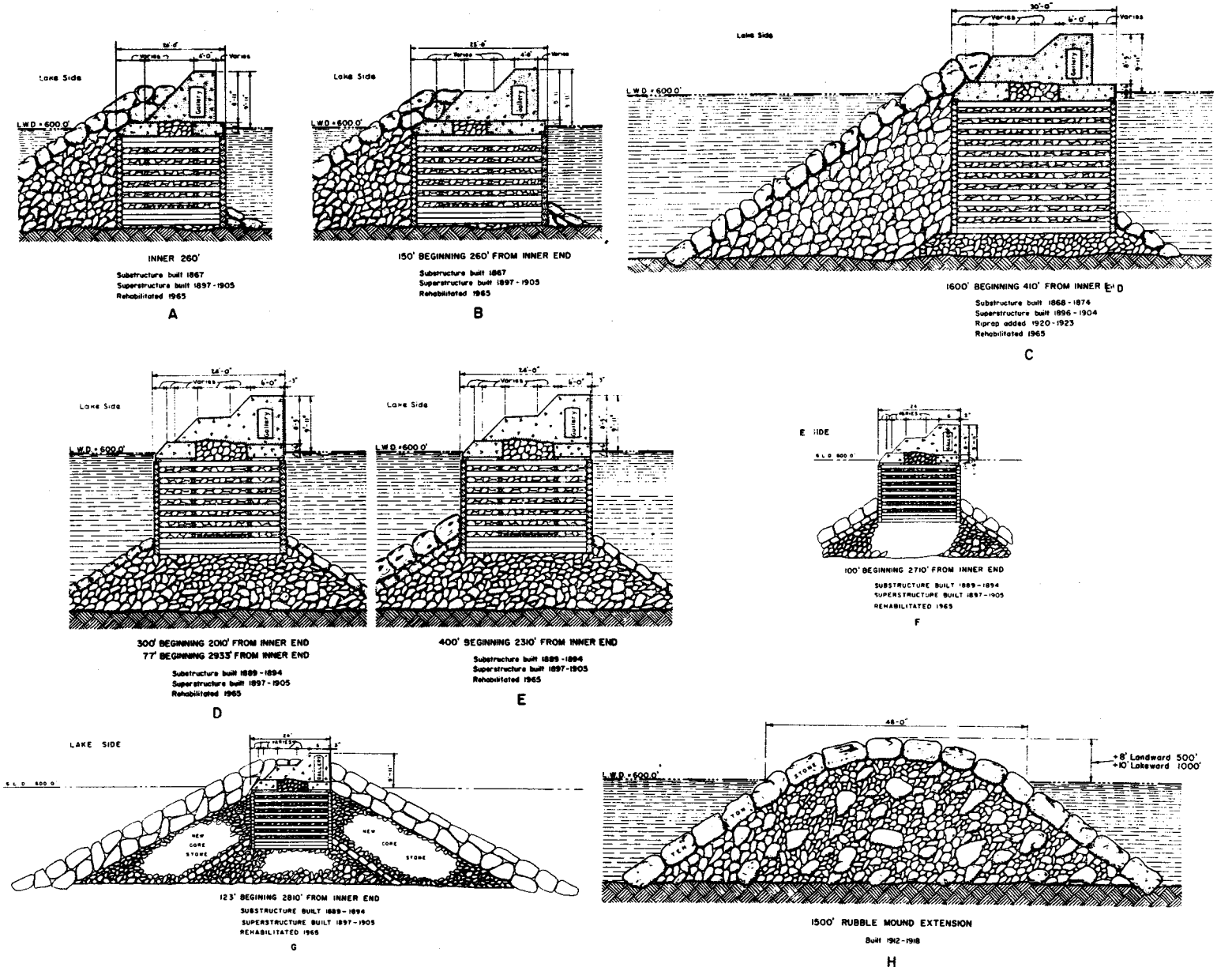


Figure 49. Typical breakwater cross sections, Marquette Harbor, Michigan

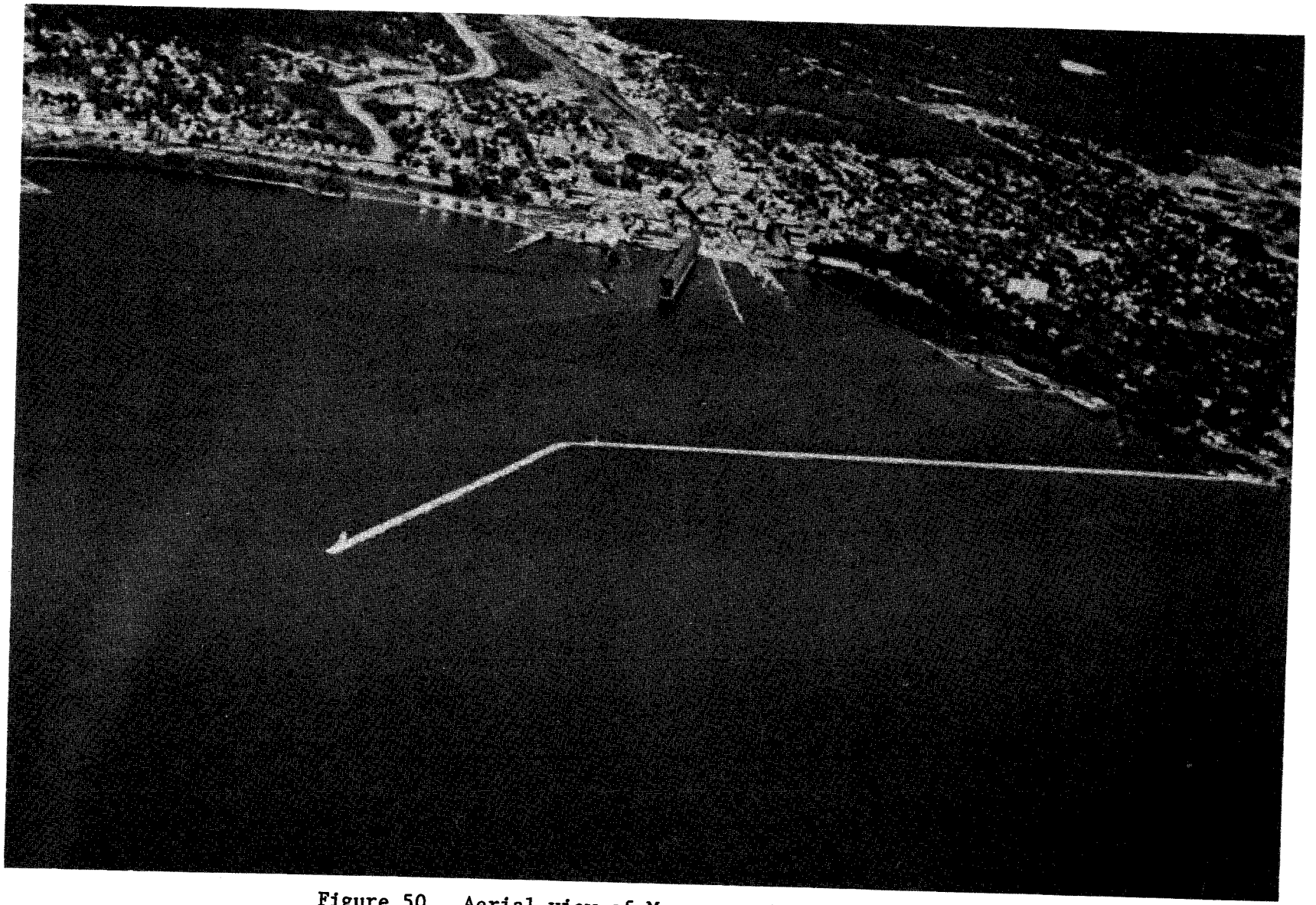


Figure 50. Aerial view of Marquette Harbor, Michigan

Table 19

Grand Marais Harbor Piers

Grand Marais, Michigan

Date(s)	Construction and Rehabilitation History
1883-1885	Construction of 700-ft-long portions of the east and west piers progressed during this time (Figures 51 and 52, Section B). It was a timber crib structure with a 20.5-ft width and was built on a stone blanket. Stone protection also was included in construction.
1885-1903	A 1,112-ft-long portion of the west pier (a timber crib structure) was constructed during this period (Figures 51 and 52, Section A). It was 24.5 ft wide. The structure was built on a stone mattress, and riprap was placed along the sides for toe protection.
1892	The inner 250-ft-long portion of the east pier and 100-ft-long portion of the west pier were completed (Figures 51 and 52, Section C). These were wood-pile structures filled with sand and stone. They were 12.5 ft wide with crest els of +6 ft lwd. Stone was placed on the channel side of the structures.
1893-1903	The outer 745-ft-long portion of the east pier (Figures 51 and 52, Section E) was constructed during this period. This was a 24-ft-wide stone-filled timber crib structure. It was built on stone, and riprap was placed on each side of the structure.
1895-1898	A 5,770-ft-long timber-pile dike (Figures 51 and 52, Section D) was constructed during this time. It was installed at an el of +4 ft lwd.
1905-1907	Stone reinforcement was added along the timber-pile dike built during 1895-98. The stone crest was 10 ft wide at an el of +4 ft lwd.
1914	Timber crib structures on the west pier (Figures 51 and 52, Section A) were repaired. Crib walls were repaired with tie rods, and 425 tons of crib-fill stone was installed in the outer 500-ft portion of the pier.
1936-1942	Repairs were made to the east and west piers (Figures 51 and 52, Section B). These included replacing decaying, broken, or missing deck planking and replenishing crib-fill stone.
1950-1951	A concrete cap (superstructure) was installed on the east pier (Figures 51 and 52, Section E). The cap extended to an el of +6 ft lwd.
1960	Construction of an 802-ft-long cellular sheet-pile breakwater extension was completed at the lakeward end of the west pier (Figures 51 and 52). The lakeward 307 ft of the structure was constructed with 58.9-ft diameter cells, and the remaining portion was built with

(Continued)

Table 19 (Concluded)

Date(s)	Construction and Rehabilitation History
	46.1-ft diameter cells. The cells were filled with dredged fill material and capped with 3-ton (minimum) cover stone. The crest el of the structure was +8 ft lwd. Riprap stone was placed around the toe of the cells.
1971	Portions of the east and west piers (Figures 51 and 52, Sections A and B) were capped with concrete. The new superstructures extended to els of +7 ft lwd.
1986	The east and west piers have undergone additional maintenance and presently are in fair condition. The pile dike, which is not included in the present project, is badly deteriorated and in ruins. *An* aerial view of Grand Marais Harbor piers is shown in Figure 53.

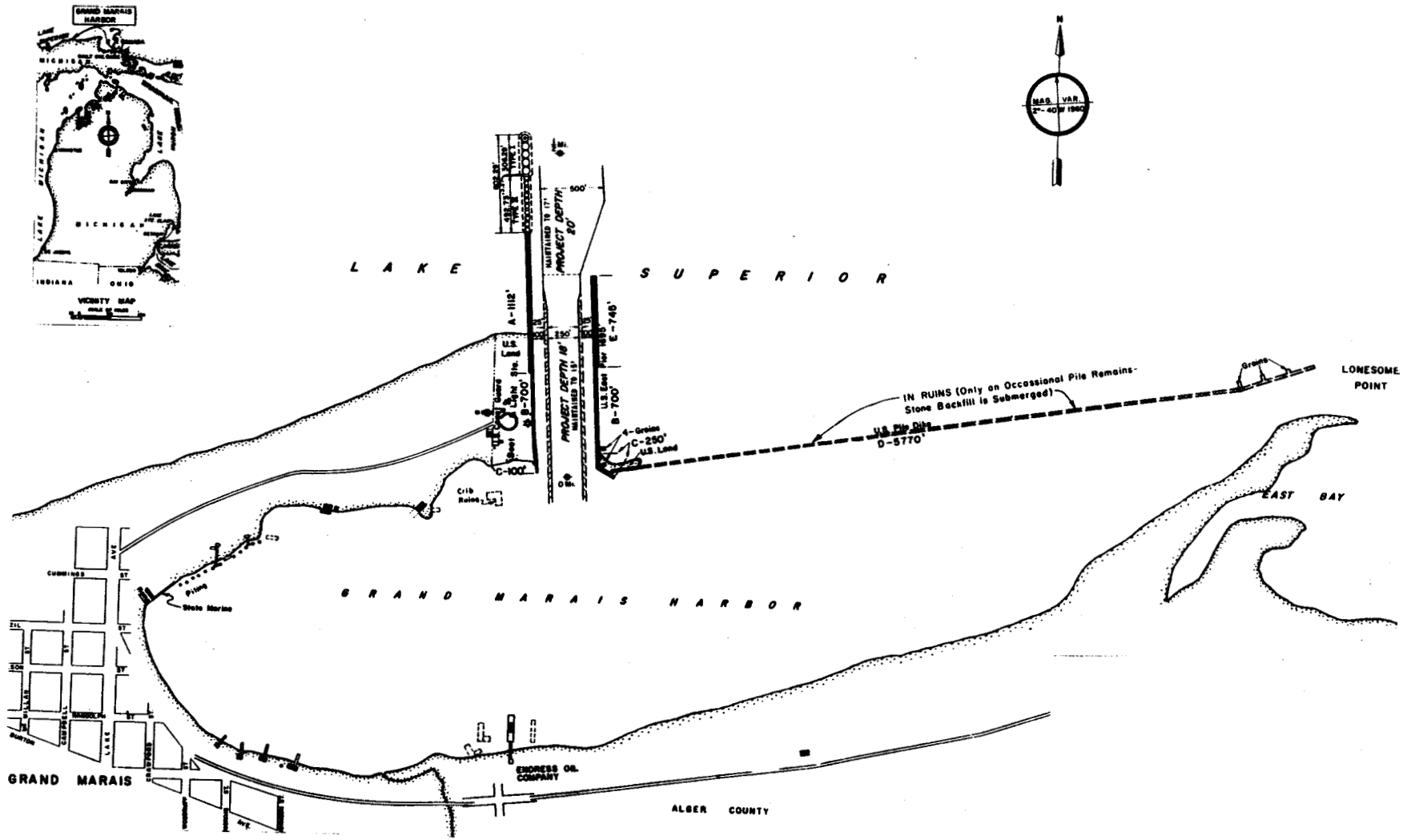


Figure 51. Grand Marais Harbor, Michigan

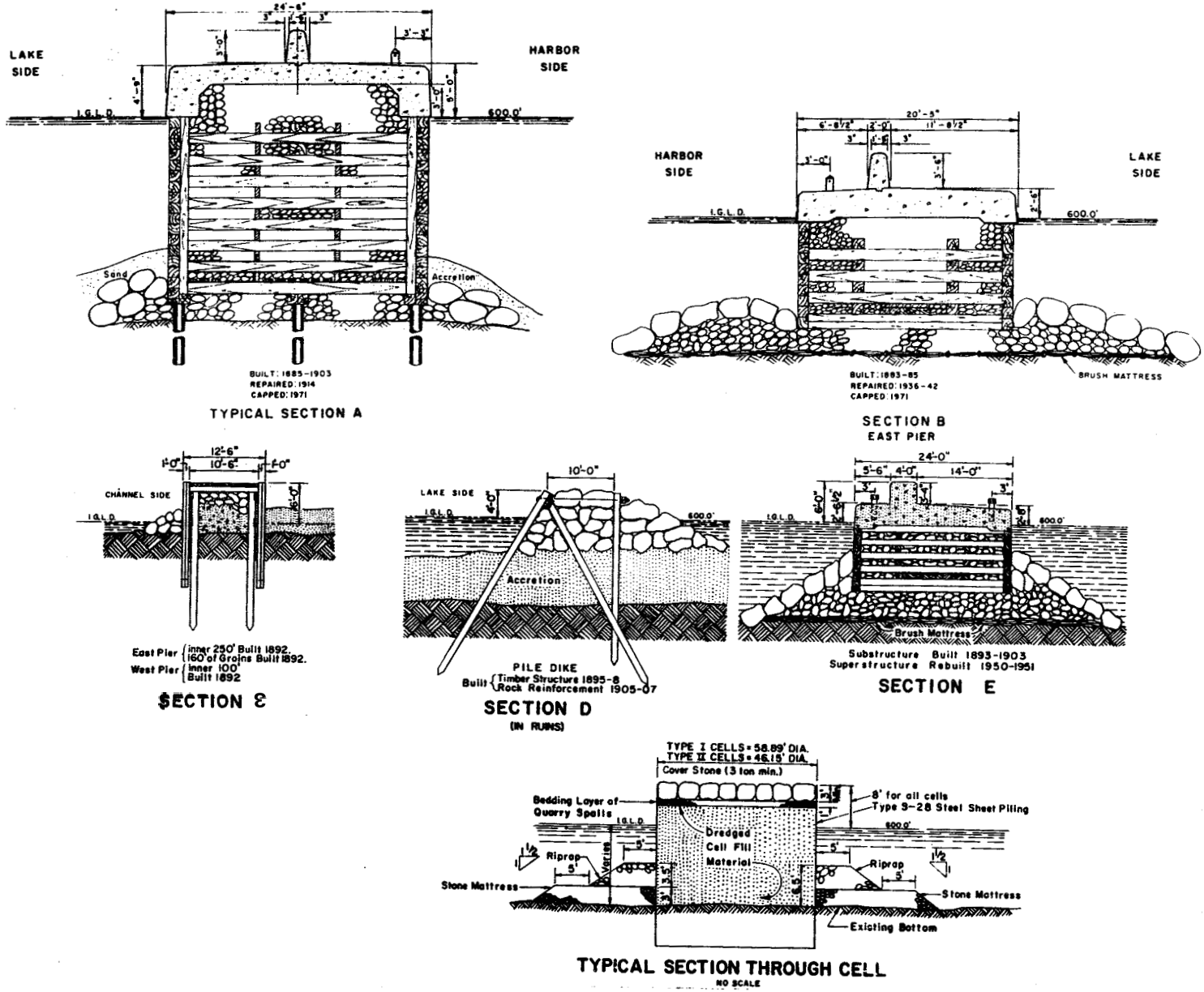


Figure 52. Typical structure cross sections, Grand Marais Harbor, Michigan

Figure 53. Aerial view of Grand Marais Harbor Michigan

Table 20

Little Lake Harbor Breakwaters

Little Lake, Michigan

Date(s)	Construction and Rehabilitation History
1964	Construction of a 270-ft-long east breakwater and a 1,000-ft-long west breakwater was completed at the site (Figure 54). These were rubble- mound structures with cellular steel sheet-pile heads. The east breakwater included 3-ton (minimum) cover stone and an 8-ft-wide crest width. The side slopes were 1V:1.75H and 1V:1.5H on the lakeside and harbor side, respectively. The elevation of the structure was +8 ft lwd from the -6 ft contour lakeward and +6 ft lwd shoreward. Stone of 5 tons (minimum) was also used (Figure 55). A 20.7-ft diameter cellular steel sheet-pile breakwater head was built on the lakeward end. The cell was sand filled and capped with asphalt. Its crest el was +8 ft lwd, and stone riprap was installed around the structure (Figure 55). The west breakwater consisted of the same cross section as the east structure (Figures 54 and 55), except portions of the breakwater were constructed of 5-ton (minimum) cover stone and 7-ton (minimum) toe stone. The west breakwater head consisted of two 36.6-ft-diameter cellular steel sheet-pile structures. The cells were sand filled and capped with 3-ton (minimum) cover stone. Their crest el was +8 ft lwd, and riprap was installed around the structures (Figure 55).
1986	The condition of the breakwaters is very good at present. The project provides protection for recreational craft; however, entrance into Little Lake during periods of storms is still hazardous because of the scattered shoals in the channel entrance. Maintenance dredging is required annually. A model study was conducted to aid in the development of the most economical plan to minimize shoaling without adversely impacting navigation (Seabergh and McCoy 1982). Construction improvements have not been performed, however.

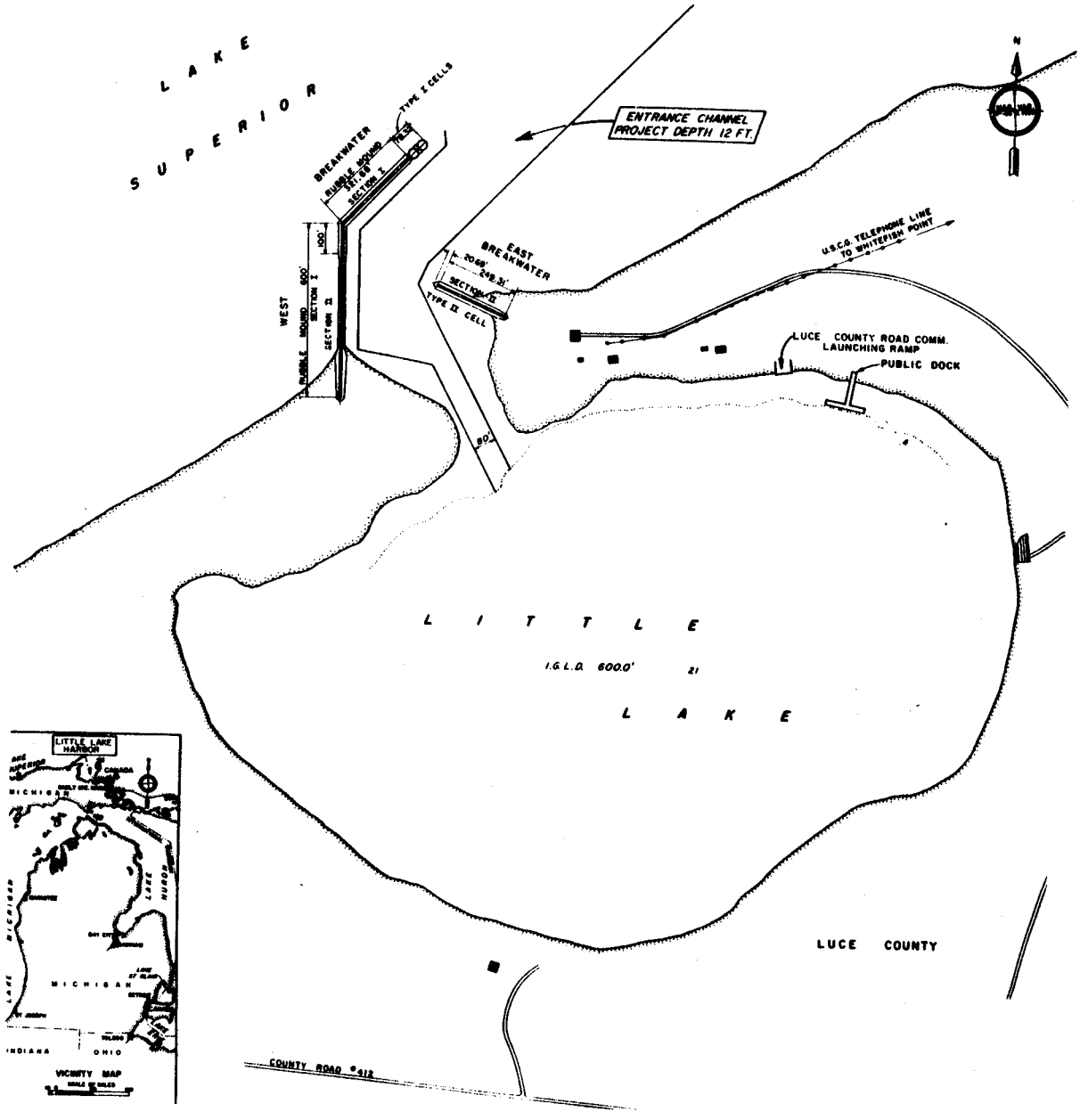


Figure 54. Little Lake Harbor, Michigan

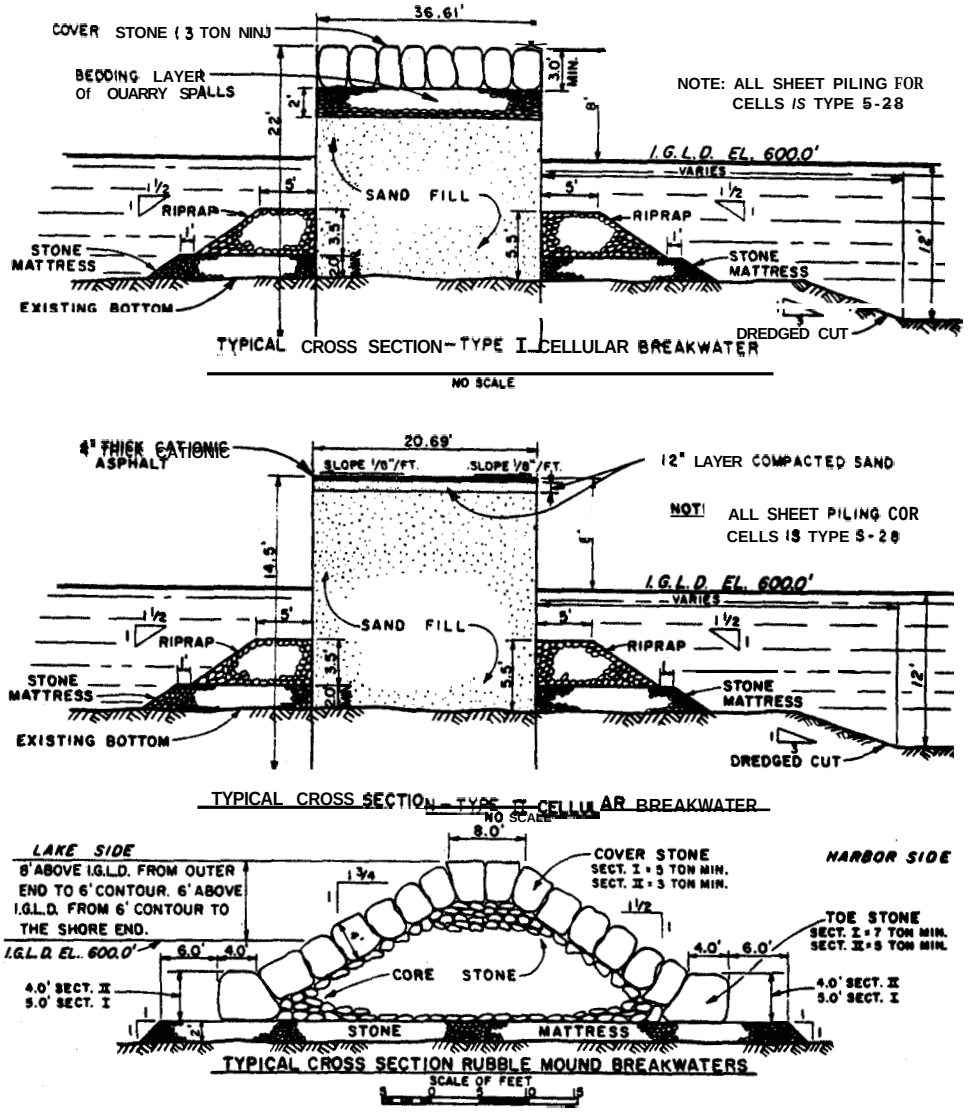


Figure 55. Typical breakwater cross sections, Little Lake Harbor, Michigan